A STUDY OF METHODS USED IN

MEASUREMENT AND ANALYSIS OF SEDIMENT LOADS IN STREAMS

SUBCOMMITTEE ON SEDIMENTATION
INTER-AGENCY
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REPORT NO. 1

FIELD PRACTICE AND EQUIPMENT USED IN SAMPLING SUSPENDED SEDIMENT

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A Study of Methods Used in

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Planned and conducted jointly by

Tennessee Valley Authority, Corps of Engineers,

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The cooperative study of methods used in

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will cover phases indicated by the following titles
of reports completed or in preparation

Report No. 1

FIELD PRACTICE AND EQUIPMENT USED IN SAMPLING SUSPENDED SEDIMENT

Report No. 2

EQUIPMENT USED FOR SAMPLING BED-LOAD AND BED-MATERIAL*

Report No. 3

ANALYTICAL STUDY OF THE ACCURACY OF METHODS OF SAMPLING
SUSPENDED SEDIMENT IN A VERTICAL SECTION*

Report No. 4

ANALYSIS OF SEDIMENT SAMPLES*

Report No. 5

LABORATORY STUDY OF SAMPLER INTAKES*

* Indicates reports are in preparation and the titles are tentative

SYNOPSIS

This report is a review of field procedure and equipment used in the past in sampling suspended sediment loads of streams. The methods following in locating sampling points across a stream and in selecting the depths of observations in a vertical, are discussed in detail, and the advantages and disadvantages of the various methods are presented. Consideration is given also to the frequency with which samples should be taken.

The devices used in the past for sampling suspended sediment are described and 65 forms are illustrated. The samplers have been classified according to their mode of action, and the advantages and objectionable features of each class are given. The requirements of a sampler which would meet all field conditions satisfactorily are set forth.

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I. INTRODUCTION

1. Present status of suspended sediment investigations--Sand, silt, gravel, and other insoluble materials transported by streams, either as suspended matter or as bed load, present problems of vital importance in many projects for flood control, soil conservation, irrigation, navigation, and water power development. Costly maintenance, loss of efficiency, and, in many cases, complete destruction of important engineering works have been experienced due to filling of reservoirs by sediment, filling or scouring in navigation and irrigation channels, and erosion and gullying on arable lands. Study has been given to these problems both in the field and in the laboratory, but a great deal more work is necessary before all of the many and complex phases can be satisfactorily handled In view of the extensive industrial, commercial, and public service development of streams accomplished in recent years, it may be expected that the accumulation and deposition of the sedimentary materials carried by rivers will become a problem even more serious in the future. Therefore, in order to effect the best solution it is desirable to have a better knowledge of the physical laws controlling sediment movement and to have more information regarding the nature and amount of sediment carried by the individual streams.

To determine the quantity, the cross-sectional distribution, and the characteristics of sediment in any river, samples of the water-sediment mixture are obtained, and analyzed in the laboratory. Many interests, public and private, and individuals, have been engaged in this type of study during the past century, but with little or no collaboration or co-ordination. Each investigator has developed equipment and sampling methods according to his own interpretation of the manner of sediment transportation and according to the demands of the particular problem at hand. Consequently, the various samplers that have been developed make up a heterogeneous collection of instruments, many radically different in principle and construction, and yet designed to perform the same work. The samplers, generally, have been improvised to meet the situation at hand and, in many cases, the construction or principle of operation prevents their obtaining samples truly representative of the quantity of sediment carried by the water in which they are inserted. Similarly, there are today many different methods used in taking suspended sediment samples for determining the sediment discharges of streams. The number and location of sampling points in a river cross section, and the frequency of sampling, have often been arbitrarily chosen without regard to periods of time, or to seasonal changes in the volume of water and sediment carried by the streams. Laboratory practices in analyzing the samples and methods of presenting the results, likewise vary. The laboratory methods employed usually have been relatively accurate, but sometimes more expensive than necessary. Uncertainty as to the best methods, and lack of standardization of apparatus and field practice, have resulted in data which are difficult to correlate and which, in many cases, are not sufficiently complete for practical use.

2. Purpose of the present investigation--In view of the miscellaneity of apparatus used in sampling the sediment content of streams, the

dissimilarity in practices employed, both in field sampling and in laboratory analysis, and in view of the importance of data regarding the quantity, character, and behavior of sediment carried by streams, several government agencies, mutually interested in this problem, have been prompted to cooperate in a joint project to review existing equipment and practices, to develop by observations and laboratory tests the relative value of results obtained in using such equipment and practices, and to develop approved methods for specific problems in sediment investigations. The first phase of this comprehensive study, which is described in this report, is an exhaustive review of equipment and field practice in securing sediment samples in this country and abroad. A similar study of bed-load samplers is a part of the project.

A study of laboratory methods for determining the concentration of sediment in the samples and the variation in size of particles, is another phase of the general project to be covered in a later report. A laboratory study of samplers, and sampler intakes, principally with consideration of the effect of their mode of action upon their accuracy, is also an important part of the investigation. These phases of the investigation will be covered in subsequent reports with titles as indicated tentatively on page 2.

Upon completion of the entire project, it is believed that improvements in field practice, in sampler design, and in laboratory analysis can be recommended. This project should serve also as a guide in establishing some degree of standardization.

3. <u>Authority and personnel</u>--The comprehensive program of which this report is a part, is conducted by an informal cooperation of the Geological

Survey, Indian Service, and Bureau of Reclamation of the U. S. Department of the Interior; the Flood Control Coordinating Committee of the U. S. Department of Agriculture; the U. S. Engineers of the War Department; and the Tennessee Valley Authority. The investigation is being conducted at the Hydraulic Laboratory of the Iowa Institute of Hydraulic Research, State University of Iowa, Iowa City, Iowa, under the supervision of Professor E. W. Lane. Engaged on the project as representatives of their respective collaborating agencies have been, Cleveland R. Horne, Jr., U. S. Engineer Department; Victor A. Koelzer, U. S. Geological Survey; Philip M. Noble and Donald E. Rhinehart, U. S. Bureau of Reclamation; Vernon J. Palmer, U. S. Department of Agriculture; and Clarence A. Boyll, Tennessee Valley Authority.

The personnel of the U. S. Engineer Sub-Office, Iowa City, and of the Hydraulic Laboratory of the University of Iowa, have assisted in the administrative details, the testing program, and in the preparation of reports. This report has been edited by Mr. Martin E. Nelson, Engineer, in charge of the U. S. Engineer Sub-Office.

4. Scope of the present report--The historical development of equipment and pertinent information concerning field practice used in sampling suspended sediment of flowing water are presented in this report. This review, which is a revision and enlargement of the preliminary report submitted in November, 1939, will form the basis for the future study and development of these phases. It is intended to be as exhaustive as is practicable, of both foreign and American literature on the subject, but due to rapid developments and advancements which are currently made in suspended sediment work, it will undoubtedly be incomplete. However, any

important information which becomes available during the course of the investigation will be covered in supplementary reports.

In Chapters II to VI are reviewed the experiences and practices of early and contemporary investigators in suspended sediment research. Investigations of the past are listed chronologically and a summary and classification of the various field methods are given.

Two highly important phases of field practice in sediment sampling are considered; viz., the location of sampling points, and the frequency of observation. The basic consideration in the selection of sampling points is that samples obtained should be representative of the quantity, or size distribution of sediment, or both, prevailing at the stream cross section at the time of sampling. The common practice has been to select one or more vertical stations in a cross section, either arbitrarily or with respect to water discharge distribution, and to take samples at one or more points in each vertical. Arbitrary selection of sampling points necessitates modifying the results by empirical coefficients. Recent practice has been to select location of sampling points on a rational basis. Various methods used in locating vertical stations and sampling points in the verticals are discussed in detail in Chapters III and IV, respectively.

Seasonal and climatic effects produce wide variations in suspended load, especially in smaller streams, and therefore, the frequency of observation is an important phase of the field procedure. In most instances it probably deserves more consideration and study than has been given to it in the past. A discussion of this factor is presented in Chapter V.

A study of suspended sediment sampling equipment, which has been or is being used, is presented in Chapters VI to X. The historical development of samplers is outlined and the various samplers are classified as to type. Their advantages and objectionable features are discussed.

Numerous samplers, varying widely in principle of action and design, have been devised. No individual sampler, or type, has been accepted commonly by the various agencies conducting sediment investigations, and, in general, samplers have not been rated with respect to their reliability in securing representative samples. Regardless of the care exercised in locating sampling points and the frequency of sampling, the data can be no more accurate than the individual samples. One purpose in this study is to determine and evaluate the ability of samplers to obtain representative water-sediment samples and, if possible, to grade samplers according to their adaptability for various types of work. Where improvements in design are indicated these will be pointed out.

5. Definition of terms--In preparing this report accepted usage of terms has been followed as closely as possible. However, in certain cases more recent information, or the necessity for more accurate definitions, has lead to departure from the usual terminology or to the introduction of new terms. The following are the definitions of certain terms as used in this report:

> Sediment--Fragmental material transported by, suspended in, or deposited by, water or air, or accumulated in beds by other natural agents. (From New Standard Dictionary, 1937, geology.)
>
> (Note--It has been common practice to use the term "silt" in this sense, but, since it also defines a certain size range of particles, it has been avoided in this report.)
>
> Suspended sediment--Sediment which remains in suspension in water for a considerable period of time without contact with the bottom.

Water-sediment--Water and sediment mixture existing in or obtained from a stream or other body of water.

Sediment concentration--Ratio of the weight of the sediment in a water-sediment mixture to the total weight of the mixture. It is ordinarily expressed in per cent for high values of concentration and in parts per million (ppm.) for low values.

Sediment discharge--Weight of sediment transported per unit of time.

Sediment hydrograph--Diagram showing the variation of sediment concentration or sediment discharge with respect to time.

Vertical--(Used as a noun). Imaginary vertical line at any point in a stream or other body of water extending from the surface to tho bottom.

Point sample--Sample of water-sediment secured at a single point either with an instantaneous or time-integrating sampler.

Time-integration--Process of sampling over a considerable period of time.

Depth-integration--Method of sampling to secure an increment of sample from every portion of a vertical.

II. FIELD PRACTICE USED IN SAMPLING SUSPENDED SEDIMENT

6. History of field practice--The field practice used in sampling suspended sediment has been found to be largely independent of the type of equipment used, and, therefore, the review of the history and development of field practice and sampling equipment will be treated separately as far as possible. This report is divided into two general parts, the first part dealing with the field practice of suspended sediment sampling and the second part with the equipment used.

In order to properly visualize the subject of field practice it is desirable first to review its history, by presenting the field practice used in the principal series of samplings in the past, from the earliest times down to the present. By such a review it is also possible to show the scientific principles underlying the present practice, beginning with the simplest aspects and gradually expanding into the more complex problems, in the natural way in which they unfolded themselves in the mind of the engineer as the science developed.

From the earliest times it was probably realized that the distribution of sediment throughout a stream is not uniform and that it is not possible to determine from a sample taken at a single point exactly the amount of sediment carried by the stream. Because of the difficulty and expense of securing and analyzing samples, however, in many of the early investigations, and, to a certain extent, in some of the more recent studies, single samples were taken and the sediment concentrations determined from them were assumed to be representative of average conditions. In other cases the concentrations were multiplied by a factor, generally based on more detailed studies, which would give a fair estimate of the total quantity of sediment discharge over a long period of time, even though it might not give an accurate value for each individual measurement. As the need of greater accuracy was felt, and more funds for observations became available, more refined methods of determining the average sediment content of a stream were developed. These refinements consisted of the selection of more than one vertical in a cross section of the stream and securing of samples from more than one point in each vertical. Thus there arose the problems of locating the verticals where they would give the most accurate results, and of finding the most desirable sampling points in those verticals. Each of these problems is treated in a chapter appropriately titled in this report.

Practically all of the earliest sediment measurements were made in large, important streams in which the sediment content, with respect to time, did not vary as rapidly, nor as widely, as in smaller streams. Although the funds available were generally insufficient to secure first-class determinations of sediment discharge, the results obtained were probably not greatly in error. However, in connection with recent studies of soil erosion, it has become necessary to measure the sediment discharge of smaller streams. There the variations in sediment concentration frequently are so rapid and extreme that the number and frequency of samplings are important considerations if results of even reasonable accuracy are to be secured. Therefore, the question of the frequency of sampling will be discussed in some detail in another chapter of this report.

The history of the development of field practice for sampling sediment of streams, as presented in the following paragraphs, has been compiled after a thorough research of existing literature on the subject.

The work done in this country is described largely in published articles but partly also in unpublished reports of various Government organizations. A thorough search of the foreign literature, together with letters and reports generously supplied by numerous individuals and organizations throughout the world, have also been reviewed. Although the review of foreign studies is undoubtedly less complete than that for developments in this country, it is believed that most of the important items from foreign countries have been included.

The large quantity of data which is available can be presented best by giving, first, a chronological record of the principal features of the various investigations, in the form of a general description and, then, in a more condensed tabular form, followed by a brief summary pointing out the principal steps in the development.

7. Development of field practice during the nineteenth century--The earliest record found in this study of suspended sediment sampling was the work of Gorsse and Subuors (26)* in 1808 and 1809 in the Rhone River at Arles, France. No description of the method of sampling was given. Blohm (4,23) sampled the Elbe River at Harburg, Germany, from 1837 to 1854, but has left no description of the method used. Although he found a slight excess of sediment near the surface, he concluded that the concentration was nearly uniform throughout the depth.

Captain Talcott of the U. S. Army collected the earliest samples from the Mississippi River (26) in 1838. No mention was made of the sampling method used.

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* Numbers refer to references in the bibliography.

From 1839 to 1846, Baumgarten (3,23) made measurements of the sediment discharge of the River Garonne at Marmande, France. This was probably the first investigation in which the sediment discharge was actually computed. Baumgarten collected single surface samples after concluding from more complete preliminary investigation that this method would give the sediment concentration representative of the mean of all depths. The same method was used by J. L. Riddell (26) in the Mississippi River near New Orleans from 1843 to 1848; by M. A. Surell (26) in the Rhone River at Lyons, France, in 1844; by Andrew Brown (26) in the Mississippi River at Natchez, Mississippi, from 1846 to 1848; by Lieutenant Marr (26) in the Mississippi at Memphis, Tennessee, in 1849; in the Mississippi at Columbus, Kentucky, (23,26,54) in 1858; and in the River Tigris, (33) Iraq (Mesopotamia) from 1918 to 1919. Jakuschoff (29) stated that in 1932 samples were taken in a similar manner in Finland and in Bavaria on the assumption that in "brisk" flow sufficient mixing will take place so that surface samples are representative of the average sediment concentration. Numerous other investigators have used a single surface sample and multiplied the resultant sediment concentration by a coefficient. The work of these investigators will be reviewed later.

In 1851 Professor Forshey (23,26,54) collected nine samples daily except Sunday from the Mississippi River at Carrollton, Louisiana, at the surface, mid-depth, and near the bottom, in verticals near each bank and at midstream. At the end of the week equal volumes of the six samples from each sampling point were combined to give nine composite samples for the week. Single surface samples were taken daily in 1852 and, on the basis of the previous measurements, the observed sediment concentration was multiplied by a coefficient of 1.2 to obtain the mean for the river. In 1867 the Board of Water Commissioners (54), St. Louis, Missouri, collected samples of water which had been pumped through the intakes of its water-works.

Adolphe Guerard (20) collected samples daily from 1869 to 1870 from the River Rhone, France, at a point 6.5 ft. below the water surface and 50 ft. from one bank.

In 1871 Patriot (23,39) collected samples from the Loire River, France, and found the relative sediment concentration at the surface, mid-depth, and bottom to be 0.9, 1.0, and 1.1, respectively.

From 1874 to 1879 Major Allan Cunningham (11,23) collected samples in the Ganges Canal, India, from nine verticals equally spaced. A tube extended to the bottom collected a column of water representing the full depth of the canal. In computing sediment discharge, the mean concentration found in each vertical was multiplied by the mean velocity in that vertical.

The U. S. Engineer Department sampled the South Pass of the Mississippi (45,46,54) continuously from 1877 to 1898. At the middle of the pass samples were taken at 0, 8, 16, and 24 ft. below the surface, and near the bottom. About 150 ft. from each shore, samples were taken at surface, mid-depth, and near the bottom.

Extensive sampling of the Mississippi and Missouri Rivers (23,54) took place from 1879 to 1881 at stations located at Carrollton, Louisiana; Columbus, Kentucky; St. Louis and St Charles, Missouri; Grafton, Illinois; Hannibal, Missouri; Clayton, Iowa; Winona, Minnesota; and Prescott, Wisconsin. Samples were collected at the surface, mid-depth, and 1 ft.

above tho bottom in eight verticals equally spaced across the stream. McMath (23,36,54) collected samples daily at St. Louis in 1879, in a similar manner except that additional samples were collected at mid-depth at a point near each bank where the total water depth was 2 ft. During the same period samples were taken (42,54) from the Mississippi River at Helena, Arkansas, at the surface and 1 ft. above the bottom, from verticals located at 1/4 and 3/4 width across the stream.

In 1889 and 1890 the U. S. Geological Survey (13) collected samples from the Rio Grande at El Paso, Texas. The samples were taken near the surface and bottom in verticals located at approximately 20, 50, and 80 per cent of the stream width. Equal volumes of all the samples were combined to determine the sediment discharge. At irregular intervals from 1897 to 1905 depth-integrated samples were taken by the International Water Commission and the U. S. Geological Survey. These samples were taken by lowering an open bottle to, but not touching, the bottom, and then raising it at a uniform rate such that the bottle would have just filled upon reaching the surface. It was considered that equal amounts of the sample were collected from equal increments of depth traversed. Samples were taken at 3-day intervals by W. W. Follett of the U. S. Geological Survey from the Rio Grande at El Paso, Texas, from 1905 to 1910, and at San Marcial, New Mexico, from 1905 to 1912. From that time until 1928 depth-integrated samples were taken by the International Water Commission at various points in the Rio Grande.

Samples were taken at intervals of 1 to 10 days, from 1893 to 1897, in the River Sutlej, Punjab, India (6,30) at each 1.0 or 1.5-ft. layer from the surface. Numerous investigations were conducted on other rivers in India at about the same time.

8. Progress from 1900 to 1930--Samples collected by the U. S. Department of Agriculture from the Brazos and Wichita Rivers in Texas (38) from 1900 to 1902 were taken at the surface, near the bottom, and at two intermediate points of a single vertical. Sediment discharge was computed from the mean of the concentrations found at those points.

Samples were taken by E. M. Dowson (7) in 1905 and 1906 from the Nile River above Wada Halfa, Egypt. The observations were made at 2-day intervals at a depth of one meter in eight verticals. The eight samples were combined and the composite was assumed to be representative of the mean in the river.

In 1906 and 1907 the U. S. Geological Survey (49) conducted sediment investigations on a number of rivers in western United States. A single sample was taken daily at a point estimated visually to represent the mean concentration, with occasional supplementary samples taken from different parts of the cross section to determine local variations.

Samples were collected from the Kistna River in Madras, India, by W. M. Ellis (7) at intervals during 1900 to 1909. The samples were taken by thrusting an open pipe vertically into the stream to collect a sample extending the full depth.

Glüschkoff (16, 29) collected samples from the Murghab River, Afghanistan, from 1907 to 1909 at the surface, mid-depth, and near the bottom of three verticals located transversely at the middle and quarter-points. The same method was used in investigations conducted by the U. S. Bureau of Reclamation (19) in the Colorado River at Yuma, Arizona, from 1909 to date. Samples were taken twice weekly during this period. No mention was made of the method of combining the samples to determine the mean daily sediment concentration. From 1909 to 1917 the sediment discharge was determined by multiplying the arithmetic mean percentage of sediment during each month by the mean monthly water discharge. From 1917 to date the sediment discharge has been computed by weighting the percentage of sediment found in each observation according to the water discharge on that day.

The Indus River Commission, India (41), collected samples from 1911 to 1920. The river cross section was divided into equal widths by four verticals. A sample was taken at mid-depth at each end vertical, and at surface, mid-depth, and bottom in the two middle verticals.

Investigations on rivers in Turkestan (17,29) in 1912 showed that the mean sediment concentration occurred at points 1/5 of the width from the banks and at 0.6 depth.

The waters of the Yangtze and Whangpoo Rivers in China (8) were sampled daily from 1912 to 1922. Samples were usually taken in one vertical at a depth of 20 ft.

Sediment measurements were conducted on the Irrawaddy River, Burma, in 1914 by B. M. Saunderson (7). Daily samples were taken at the surface, mid-depth, and near the bottom in each of eight verticals. Equal volumes of tho eight surface samples were combined. Similarly, composites of the mid-depth and bottom samples were made up and analyzed.

The Neuquen River, Argentina (2), was sampled from 1915 to 1918 at one point, 0.5 meter below the surface.

The U. S. Department of Agriculture (14) collected samples twice monthly from the Colorado River in 1917 and 1918. Samples were taken at the surface, mid-depth, and bottom of verticals located transversely at the quarter and mid-points. If the stream depth was not more than 2 to 3 ft., only surface and bottom samples were taken and if the depth was less than 2 ft. only a mid-depth sample was collected.

Samples were collected from the Nile River (5) in Egypt from 1918 to 1921, evidently for research purposes, at intervals of one meter in the vertical, the total depth of water being approximately 10 meters. The horizontal distribution of sampling points was not mentioned in the reference reviewed.

The U. S. Geological Survey has collected samples from the Colorado River and its tributaries from 1925 to the present time. The work of the first three years on the main Colorado River has been published (25). In the early work, samples were taken at points about 1.5 ft. above the bottom of the river and about 1 ft. below the surface in addition to depth-integrated samples. The depth-integrated samples were used to compute sediment discharge unless they appeared erratic. In such cases, the average of the concentrations in the surface and bottom samples was used. Since 1928 most of the samples collected in the Colorado River and its tributaries have been of the depth-integrated type. A sampler was used which permitted lowering the bottle to the bottom with the bottle closed. The stopper was removed from the bottle and the bottle then pulled to the surface at a uniform rate so that it was not quite full when it reached the surface. At certain periods of the year, at the Grand Canyon gaging station and, under certain conditions, at other stations, the depth was not sufficient to warrant the use of the stopper pulling device so that the bottle was lowered and raised with the stopper removed, the rate of lowering and raising being such as to bring the bottle to the surface not quite full.

The U. S. Department of Agriculture (12), in collecting samples from Texas streams from 1924 to 1930, assumed the concentration at 0.6 depth to represent the mean in a vertical and the average at 1/6, 1/2, and 5/6 width to represent the mean for the cross section. The selection of these points was based on a series of more complete determinations of sediment concentration and discharge of the Brazos River, Texas. Values of sediment discharge determined by samples taken at these points, when compared to the more accurately determined values, were found to be within the limits of error considered permissible in measuring water discharge.

From 1928 to date, samples have been taken by the U. S. Geological Survey in cooperation with the International Water Commission (27) from the Rio Grande at Eagle Pass, Texas. Surface samples were taken daily at 1/6, 1/2, and 5/6 width, and equal volumes were combined to obtain a composite sample assumed to represent the mean of the cross section. Earlier experiments by the U. S. Department of Agriculture showed that surface samples represented 0.91 of the mean suspended sediment concentration in the vertical within reasonable limits of accuracy. This factor was used in this investigation. Depth integrated samples were taken daily at San Marcial, New Mexico, by the same organizations. Recently, to eliminate daily analysis of samples in these investigations, portions of each daily sample have been combined and the analysis of composite samples are made at the end of a given period. The volume of each daily sample to be combined is proportional to the water discharge for the day on which it was collected. Jakuschoff (29) states that this method of combination of samples has been used in Europe.

9. <u>Progress during the last decade</u>--The U. S. Engineer Department (55) collected numerous samples from the lower Mississippi and its tributaries in 1930 and 1931. Samples were generally taken about three times each week at the surface, mid-depth, and near the bottom in each of eight verticals. From the average of thousands of water discharge measurements taken previously in the Mississippi River, it was found that the upper 1/4, the middle 1/2, and the lower 1/4 of a given cross section carried 27.2, 51.2, and 21.6 per cent, respectively, of the total water discharge. Hence, weights of 1, 2, and 1 were applied to values of suspended sediment concentration observed at the surface, mid-depth, and bottom layers, respectively.

The Missouri River Division of the U.S. Engineer Department collected samples from the Missouri River and tributaries in 1929 and 1930, under the direction of Dr. L. G. Straub. At the main stations, samples were taken at 0.2 and 0.8 depths with weights of 5 and 3, respectively, applied to the sediment concentration observed at those depths to obtain the mean in the vertical. Verticals were chosen at uniform intervals transversely with a minimum distance between them of 4 ft. and a maximum of 150 ft. At minor stations single surface samples were taken at mid-stream and coefficient of 1.1 to 1.2 was applied to obtain the mean. The choice of points in the vertical and the coefficients to be applied were based on rational derivation by Dr. Straub, verified by experimentation (50), as explained in Section 19.

Daily samples were taken by the St. Paul U. S. Engineer District (53) from the upper Mississippi and its tributaries during 1930-1933. At most of the stations single surface samples were taken and the observed concentrations were multiplied by a coefficient. The coefficient of 1.15 was used for all rivers except the Chippewa River, where 5.0 was found necessary, and the Black and Wisconsin Rivers, where 1.4 was applied. The coefficients were determined by occasional precise measurements, in which samples were taken at a depth of 1 ft., at 0.2, 0.6, and 0.8 depth, and 1 ft. above the bottom. At some of the more important stations the Straub method was used.

For several years prior to 1934, samples were collected daily from the Indus River in India (30). Samples were taken at the surface, mid-depth, and bottom of four verticals.

On the basis of experiments on the Po River, Italy, in 1930 and 1932, Giandotti (15,57) found that samples taken at mid-depth gave errors ranging from 6 per cent at high gage heights to 14 per cent at low gage heights. Daily samples were collected from the Po at a point one meter below the surface in three verticals located near each bank and near mid-stream.

Hjulstrom (22) directed investigations on the Fyris River in Sweden from 1929 to 1934, where single samples were taken daily in midstream at a depth of 1.5 meters. The range of depth of the river at the sampling point was apparently from 4 to 7.5 meters. From preceding investigations, wherein samples were taken at six points in each of nine verticals, it was found that a coefficient of 1.15 could be applied to the sediment concentration of the single sample to obtain the mean concentration for the river.

From 1930 to 1932, in the Jamrao Canal System (21), Bombay, India, a single sample at 0.6 depth was taken as being representative of the sediment concentration of the entire canal.

Samples were taken by engineers of the Soviet Union in 1932 from the Boz-Su Irrigation Canal near Tashkent, Central Asia (28) in three main verticals located at 1/4, 1/2, and 3/4 width, and in two side verticals. In the main verticals sampling points were chosen at 0.2, 0.6, and 0.8 depth and near the bottom while at the side verticals only the 0.6 depth was sampled.

The Philadelphia U. S. Engineer District conducted extensive investigations during 1931-1934. On the lower Delaware and Christiana Rivers, samples were taken at 5-ft. intervals vertically and at 15-min. time intervals during ebb and flood tides. From the upland portion of the Schuykill River samples were taken at 0.6 depth in a single vertical located at the point of deepest water. These samples were taken at 30-min. intervals during a period of one week at each station on the river.

In 1937 the St. Paul U. S. Engineer District (52) used a method of sampling developed by Mr. J. P. Luby of that office. The samples were taken at points spaced vertically in such a manner that each sample represented a proportional part of the total discharge in the vertical. This method of spacing the points will be described in Section 20. Five points in each vertical were chosen by Mr. Luby for investigations on the upper Mississippi River and its tributaries. The points at which the samples were to be taken were determined by this method to be 8.7, 26, 44, 63, and 87 per cent of the total depth. From three to nine verticals were usually chosen.

The Vicksburg U. S. Engineer District (56) collected samples from the Mississippi River in 1937 and 1938 at irregular intervals for research purposes. Points were chosen at 0.2, 0.4, 0.6, and 0.8 depth, at the bottom and at a distance of 1, 2, and 4 ft. from the bottom. Verticals were located by the party chief with consideration of the variation in the channel cross section and velocities.

Samples for research purposes were collected from the Mississippi River at Chester, Illinois, in 1938 by the St. Louis Division of the U. S. Engineer Department. Samples and velocity measurements were taken simultaneously at 0.1, 0.3, 0.5, 0.7, and 0.9 depth in each of seven verticals. This method of measurement will be described further in Section 18. The same method was used by the First New Orleans District of the U. S. Engineer Department in 1938, in the passes near the mouth of the river with six to eight verticals of eight to twelve points each.

The Providence U. S. Engineer District collected samples from the Connecticut River in 1938. Depth-integrated samples were taken at the upper and lower ends of 31 bars. At five other stations on the river, samples were taken twice daily, at the surface, mid-depth, and near the bottom of verticals located at the 1/4, 1/2, and 3/4 width.

10. Present practice in sampling suspended sediment--Since 1934 the Tennessee Valley Authority has conducted correlated investigations of sediment discharge at numerous stations in the Tennessee River. Samples were taken at the surface, mid-depth, and near the bottom of verticals estimated to be at the middle of sections of equal discharge. The number of verticals chosen by the field engineer depended upon the size, stage, and sediment distribution of the stream. Samples were analyzed individually

for sediment concentration, and in computing the mean, the mid-depth concentration was given double weight. Under ordinary conditions samples are taken weekly but during freshets and floods they are taken at 4 to 12 hr. intervals on the rise and at 12 to 48-hr. intervals after the peak.

The practice of the U. S. Bureau of Reclamation in taking samples from the Colorado River in Arizona is to sample at surface, mid-depth, and bottom in each of three or four verticals. The verticals are chosen at points estimated to be the mid-points of sections of equal discharge.

The International Water Commission takes surface samples in the Rio Grande at Eagle Pass, Texas, at 1/6, 1/2, and 5/6 width, applying a coefficient of 1.1 to the sediment concentration indicated by the mean. At San Marcial, New Mexico, depth-integrated samples are taken by this organization.

The present practice of the U. S. Geological Survey (9) is to take depth-integrated samples for routine observations. Point samples are sometimes taken for special investigations.

The Forest Service of the U. S. Department of Agriculture conducts investigations on seven rivers in North Carolina and Tennessee. Samples, including one at the bottom, are taken at several points in each of several verticals. The number of points and frequency of sampling depends upon the stage.

The present practice on the Tarkio Soil Conservation Service Project is to take depth-integrated samples in three verticals except for high stages, when more verticals are chosen. Daily samples are taken for moderate flows of less than 10 c.f.s. unless there is considerable fluctuation in the water discharge or sediment concentration. During rapidly changing stages hourly samples are recommended.

Samples are taken at present in the Punjab, India (51), from a single point in midstream located at 0.6 depth. Previous measurements in which samples were taken at each 10 per cent of the depth have indicated that the mean concentration in the vertical occurs at 0.6 depth.

Present practice of the Irrigation Department, Union of South Africa, is to collect a single sample from a point 1.0 to 1.5 ft. below the water surface which is assumed to be representative of the cross section. Samples are usually taken once or twice daily by resident observers.

The Little Rock U. S. Engineer District is conducting investigations on numerous rivers in Oklahoma, Kansas, Colorado, Arkansas, Missouri, and northern Texas. Daily surface samples are collected by resident observers at some of the stations. These are collected at midstream, if the stream is less than 100 ft. wide, and at 1/6, 1/2, and 5/6 width if it is wider than 100 ft. At most of the stations, samples are taken only at the time of a discharge measurement, which is made generally once a week. Samples are taken at 0.6 depth at 1/6, 1/2, and 5/6 width. For intermediate and high stages, samples are taken at three points in the three verticals.

Samples are collected in the Fort Peck U. S. Engineer District using the Luby method with five points in verticals located at 1/4, 1/2, and 3/4 width. During low flows samples are taken at only the 0.2, 0.6, and 0.8 depth in the three verticals. In both methods two samples are taken at each point and all the samples are combined for analysis. Measurements are made daily during the spring high water and weekly throughout the remainder of the year, except during the winter months when the observations are discontinued.

In the Omaha U. S. Engineer District resident observers collect surface samples weekly from midstream. Samples are taken more often during rapidly changing stages and when a noticeable change in sediment concentration occurs. In addition, samples are taken at three to five points in the vertical each week. The samples are combined for analysis and the results are compared with the surface concentration to compute sediment discharge from the single surface sample.

Depth-integrated samples are collected by the Rock Island U. S. Engineer District, resident observers being employed for some of the work. Several verticals are generally selected and are spaced so as to be representative of equal volumes of flow. All samples are combined in equal volume to form a single composite sample for analysis. In the future, in some cases, a single vertical will be sampled and its relation to the entire stream determined by occasional composite samples.

The South Atlantic Division of the U. S. Engineer Department collects samples in the Savannah River and in Savannah Harbor. In the river, samples are taken daily at the surface, mid-depth, and bottom. In the harbor, samples are collected at the same points at high tide, 1/4, 1/2, and 3/4 ebb, and at low tide.

The Great Lakes Division of the U. S. Engineer Department is contemplating sampling along the shoreline of Lake Erie. Samples will be taken at 0.5-ft. intervals vertically and at 10-ft. intervals horizontally with a small sampler, and at 500-ft. intervals with a larger sampler.

The Vicksburg U. S. Engineer District collects samples on nine tributaries of the lower Mississippi River. Samples are taken weekly and more often during rapidly changing stages. One to four samples are taken in each of four to seven verticals.

The South Pacific Division of the U. S. Engineer Department collects samples from the American and Yuma Rivers and from San Francisco Bay. Samples are collected in the rivers about three times each week.

11. <u>Brief summary of the history of field practice</u>--A condensed summary of the preceding data, showing the historical development of field practice in sampling suspended sediment in streams, is presented in Table 1, giving for each investigation, the date, the river and location, the name of the investigator, and the reference to the source of the information. The frequency of sampling, the type of sampler, the location of the verticals sampled, the location of sampling points in the vertical, the coefficient used, if any, and the basis for selecting the coefficient are also given.

Although much practical knowledge of sediment was no doubt obtained by the Chinese and Egyptians at an early date, as far as our knowledge of sediment sampling metnods is concerned, the history goes back not more than a century and a third, and no information seems to have been handed down from the earlier civilizations. The first samplings of which records are available were taken by Gorsse and Subuors on the Rhone River in France in 1808 and 1809, and the first known computations of the amount of sediment carried by a stream over a period of years was made by Baumgarten on the Garonne River in France, from 1839 to 1846. Although the possibility that surface samples might have a lesser concentration than the average in the stream was discussed as early as 1839, no record of routine measurements other than surface samples has been found prior to those taken by Forshey in the Mississippi at Carrollton, Louisiana, in 1851. These measurements are also the first recorded where observations

TABLE 1

TABULAR HISTORY OF SUSPENDED SEDIMENT INVESTIGATIONS

Date	River and location	Investigator and reference number	Frequency of sampling	Sampler	Number and location of verticals	Sampling points in vertical: Location*	Coefficient	Basis of choice
1808-09	Rhone - France	Gorsse & Subuors (26)						
1837-54	Elbe - Germany	Blohm (4,23)						
1838	Mississippi	Talcott (26)						
1839-41	Garonne - France	Baumgarten (3,23)			Single vertical	Surface	1.0	Prelim. measure.
1843-48	Mississippi - New Orleans	Riddell (26)	Infrequently 1843-45, 3-day intervals 1846	Pail	Single vertical	Surface	1.0	
1844	Rhone - France	Surell (26)			Single vertical	Surface	1.0	
1846-48	Mississippi - Natchez	Andrew Brown (26)	484 samples in 24 months		Single vertical	Surface	1.0	
1849	Mississippi - Memphis	Lt. Marr (26)	Daily		Single vertical	Surface	1.0	
1851	Mississippi - Carrollton	Forshey (23,26,54)	Daily (except Sunday)	Keg	Middle and near banks	0,0.5,1.0 depth	Equal weights	
1852	Mississippi - Carrollton	Forshey (23,26,54)	Daily (except Sunday)	Keg	1 point 400 ft. from bank.	Surface	1.2	Prelim. measure.
1858	Mississippi - Columbus	U.S.E.D. (23,26,54)	Irregular intervals		Single vertical	Surface	1.2	
1867	Mississippi - St. Louis	Board of Water Commissioners (54)		Pumped at waterworks intake.				
1869-70	Rhone - France	Guerard (20)	Daily		1 point 50 ft. from bank	6.5 ft. depth	1.0	
1871	Loire - France	Patriot (23,39)				0,0.5,1.0 depth		
1874-79	Ganges Canal - India	Cunningham (11,23)		Vertical pipe extending full depth.	9 equally spaced	Sample from entire vertical		
1879-81	Miss. & Missouri - 9 stations from Minn. to La.	U.S.E.D. (23,54)		Pail at surface, slip bottle at other points, Fig. 15.	8 equally spaced	0,0.6 depth and 1 ft. above bottom.		
1879	Mississippi - St. Louis	McMath (23,36,54)	Daily		Near each bank & 8 equally spaced	0,0.5,1.0 depth		
1879	Mississippi - Helena	Johnson (42,54)		Johnson vertical pipe, Fig. 9.	1/4 & 3/4 width	Surface & 1 ft. above bottom		
1877-98	Mississippi - South Pass	U.S.E.D. (45,46,54)	Twice weekly		Midstream 150 ft. from banks	0,8,16,& 24 ft. depth and at bottom. 0,0.5,1.0 depth.		
1889-90	Rio Grande - El Paso	U.S.G.S. (13)		Horizontal trap	Approx. 0.2,0.5, 0.8 width	Surface & bottom		

1893-97	Sutlej - India	Kennedy (6,30)	Intervals of 1-10 days			1.0 or 1.5-ft. intervals		
1897-1905	Rio Grande - Texas	U.S.G.S. & I.W.C.(13)	Irregular intervals	Open bottle		Depth-integrated		
1900-02	Brazos & Wichita - Texas	U.S.D.A. (38)	Intervals of 1-90 days	Horizontal trap	Midstream	Surface, bottom & 2 intermediate	Equal weights	
1905-06	Nile - Wada Halfa, Egypt	Dowson (7)	2-day intervals		8 equally spaced	1.0-meter depth	1.0	
1905-10	Rio Grande - El Paso	Follett (U.S.G.S)(13)	3-day intervals					
1905-12	Rio Grande - San Marcial	Follett (U.S.G.S)(13)	3-day intervals					
1906-07	Rivers of Western U. S.	U.S.G.S. (49)	Daily	Bottle	Single vertical estimated to be mean	Surface	1.0	
1907-09	Murghab - Afghanistan	Gluschkoff (16,29)			1/4,1/2,3/4 width	0,0.5,1.0 depth		
1900-09	Kistna - Madras, India	Ellis (7)		Vertical pipe extending full depth		Sample from entire vertical	1.0	
1909-Date	Colorado - Yuma, Arizona	U.S.B.R. (19)	Twice weekly	Tait-Binckley, Fig. 31	1/4,1/2,3/4 width	0,0.5,1.0 depth		
1911-20	Indus - India	Indus R. Commission(41)			4 verticals	0,0.5,1.0 depth (only 0.5 depth at end verticals)		
1912	Rivers in Turkestan	(17,29)			Single vertical at 1/5 width	0.6 depth	1.0	Prelim. measure.
1912-22	Yangtze & Whangpoo-China	Chatley (8)	Daily		Midstream	20-ft. depth		
1912-28	Rio Grande - Texas	I.W.C. (27)		Bottle		Depth-integrated	1.0	
1914	Irrawaddy - Burma	Saunderson (7)	Daily	Vertical pipe type	8 points	0,0.5,1.0 depth		
1915-18	Neuquen - Argentina	Ballester (2)			Single vertical	0.5 meter depth	1.0	
1917-18	Colorado - Arizona	U.S.D.A. (14)	Twice monthly	Yuma, Fig. 46, for routine; Tait-Binckley, Fig. 31, as check.	1/4,1/2,3/4 width	0,0.5,1.0 depth 0,1.0 depth if depth = 2 to 3 ft.		
1918-19	Tigris - Iraq	Lewis (33)	Daily	Simple can	Single vertical	Surface		
1918-21	Nile - Egypt	A.B. Buckley (5)				1.0 meter intervals		
1924-30	Streams in Texas	U.S.D.A. (12)	Daily	U.S.D.A. bottle sampler, Fig. 56	1/6,1/2,5/6 width	0.6 depth	1.0	Prelim. meas. on Brazos R.
1925-28	Colorado - Arizona	U.S.G.S. (25)	Generally 3 times weekly	Colorado sampler, Fig. 57	1/4,1/2,3/4 width	Integrated, surface & 1.5 ft. above bottom	1.0	
1928-Date	Colorado - Arizona	U.S.G.S. (25)	Generally 3 times weekly	Colorado sampler, Fig. 57	1/4,1/2,3/4 width	Depth-integrated	1.0	
1928-Date	Rio Grande - Eagle Pass	U.S.G.S. & I.W.C. (27)	Daily	Small necked bottle	1/6,1/2,5/6 width	Surface	1.1	Prelim. measure.
1928-Date	Rio Grande - San Marcial	U.S.G.S. & I.W.C. (27)	Daily	Small necked bottle		Depth-integrated	1.0	
1929-30	Missouri & Tributaries	U.S.E.D. (50)	Daily	Straub Sampler Fig. 58	Evenly spaced, weighted according to water dis.	1 ft., 0.2,0.5, 0.8 depth & 1 ft. above bottom.		Combined with vel. & precisely computed.
1929-30	Missouri & Tributaries	U.S.E.D. (50)	Daily	Straub Sampler Fig. 58	Not<4 verticals Not>150ft. spacing.	0.2 & 0.8 depth.	5/8,3/8	Theory & prelim. meas.

TABLE 1

TABULAR HISTORY OF SUSPENDED SEDIMENT INVESTIGATIONS

Date	River and location	Investigator and reference number	Frequency of sampling	Sampler	Number and location of verticals	Sampling points in vertical: Location*	Coefficient	Basis of choice
1929-30	Missouri & Tributaries	U.S.E.D. (50)	Daily	Straub Sampler Fig. 58	Midstream	Surface	1.1-1.2	Precise meas.
1929-34	Fyris - Sweden	Hjulstrom (22)	Daily	Bottle sampler Fig. 45	Midstream	1.5 meter depth	1.15	Prelim. meas. at 6 pts. in ea. of 9 verticals.
1930-31	Mississippi & Tributaries	U.S.E.D. (55)	About 3 times weekly	Vertical pipe Fig. 11	8 equally spaced	0,0.5,1.0 depth	1/4,1/2 & 1/4	Prev. water disch. meas.
1930-32	Jamrao Canals - Bombay	(21)			Single vertical	0.6 depth	1.0	
Previous 1934	Indus - India	Hawes (30)	Daily	Copper bottle Fig. 44	4 verticals	0,0.5,1.0 depth		
1930-32	Po - Italy	Giandotti (15,57)	Daily	Pumping sampler Fig. 72	3 verticals	1.0 meter depth	1.0	Prelim. meas.
1930-33	St. Paul District	U.S.E.D. (53)	Daily	Bottle sampler Fig. 54	Not<4verticals Not>150ft. spacing.	0.2 & 0.8 depth	0.6&0.4	Approx. of Straub coeff.
1930-33	St. Paul District	U.S.E.D. (53)	Daily	Bottle sampler Fig. 54	Single vertical	Surface	1.15-5.0	Prelim. meas.
1931-34	Lower Delaware and Christiana Rivers	U.S.E.D.	15-min. intervals during ebb and flood tides	Bottle & Philadelphia Fig. 50		5-ft. intervals		
1931-34	Schuylkill River stations	U.S.E.D.	1/2-hr. intervals (for 1 wk.)	Bottle & Philadelphia Fig. 50	Point of deepest water	0.6 depth	1.0	
1932	Boz-Su Canal, Tash Kent, Asia	Jagodin (28)		Jankowsky horiz. Fig. 25	At 1/4,1/2,3/4 width At 2 add. side verticals	0,0.2,0.6,0.8, 1.0 depth 0.6 depth		
1932	Rivers in Finland & Bavaria	(29)		Hochstetter Fig. 51	Single point	Surface	1.0	
1934-Date	Tennessee & Tributaries	T.V.A.	Weekly, more often during changes in stage.	TVA horizontal Figs. 33 to 36.	2 to 7 verticals **	0,0.5,1.0 depth	1/4,1/2 & 1/4	
1937	Upper Mississippi Valley Division	U.S.E.D. (52)	Irregular intervals	Bottle sampler Fig. 54	3 to 9 verticals equally spaced	8.7,26,44,63, & 87% of depth	Equal weights	Rational
1937-38	Mississippi - Vicksburg District	U.S.E.D. (56)	Irregular intervals (research)	Vertical pipe & horiz. Figs. 11 & 36, Respect.	4 to 7 verticals	0.2,0.4,0.6,0.8 depth & 1,2, & 4 ft. above bed		Combined with vel. (precise computation)
1938	Mississippi - Chester, Ill.	U.S.E.D.	do.		7 points	0.1,0.3,0.5,0.7 0.9 depth		do.
1938	Mississippi - near mouth	U.S.E.D.	do.		6-8 points	8-12 points		do.
1938	Connecticut River, Providence District	U.S.E.D.	Twice daily	Bottle	1/4,1/2,3/4 width	0,0.5,1.0 depth		
Present	Mississippi River Rock Island District	U.S.E.D.		Tait-Binckley Fig. 31 Colorado - Fig. 57 Integrating, simplied Fig. 66; Integrating Fig. 69.	Several **	Depth-integrated	1.0	
do	Little Rock District	U.S.E.D.	Weekly (hydrographer	U.S.D.A. bottle Fig. 56	1/6,1/2,5/6 width	0.6 depth	1.0	Previous U.S.D.A. measurements of 1924-30
do	Little Rock District	U.S.E.D.	Daily (Resident observer)	do	Middle if width <100 ft. 1/6,1/2,5/6 width if>100ft.	Surface		

do	South Pacific Division	U.S.E.D.	3 times weekly	Horizontal Fig. 28 and bottle				
do	South Atlantic Division	U.S.E.D.	Daily	Bottle Fig. 48		0,0.5,1.0 depth		
do	Great Lakes Division (Lake Erie)	U.S.E.D.				0.5 ft. intervals		
do	Fort Peck District	U.S.E.D.	Depends on season	Straub Sampler Fig. 58	Not<3 verticals	8.7,26,44,63, & 87% of depth	Equal weights	Rational
do	Vicksburg District	U.S.E.D.	Weekly with increased frequency during rapidly changing stage	Horizontal toggle Fig. 39	4 to 7 verticals	1 to 4 points		
do	Omaha District	U.S.E.D.	Weekly with extra samples for change in stage or sediment	Omaha, Fig. 68		Surface or 3 to 5 points		
do	(Routine)	U.S.G.S. (9)		Bottle, Fig. 55 Colorado, Fig. 57		Depth-integrated	1.0	
do	Colorado - Arizona	U.S.B.R.		U.S.B.R., Fig. 53 Tait-Binckley, Fig. 31 Tuma, Fig. 46	3 or 4 verticals**	0,0.5,1.0 depth	Equal weights	
do	7 rivers in North Carolina and Tennessee	Forest Service U.S.D.A.	Depends on stage	Horizontal Fig. 29	Several	Several		
do	Punjab, India	Punjab Irrigation Research Institute (51)		Bottle, Fig. 49	Midstream	0.6 depth	1.0	Prelim. measure.
do	Tarkio Project, Missouri	S.C.S. & U.S.G.S.	Daily but more often for noticeable variations	Bottle, Fig. 55	Generally 3 verticals, more during floods	Depth-integrated	1.0	
do	South Africa	Irrigation Dept.	Once or twice daily		Single vertical	1.0 to 1.5 ft. depth	1.0	

* Samples noted bottom were generally taken a short distance above the bottom.
**Verticals were chosen at points estimated visually to be the midpoints of sections of equal discharge.

ABBREVIATIONS

U.S.D.A. - U. S. Department of Agriculture
U.S.E.D. - U. S. Engineer Department
U.S.G.S. - U. S. Geological Survey
U.S.B.R. - U. S. Bureau of Reclamation
I.W.C. - International Water Commission
S.C.S. - Soil Conservation Service

were taken in more than one vertical. In this case the verticals were taken in midstream and near each bank. The oldest record found of a quantitative method of locating verticals, other than at the center, is that used by Gluschkoff on the Murghab River in Afghanistan in 1907, where verticals were placed at the 1/4, 1/2, and 3/4 width across the stream, or at equal distances apart. Since that time the practice of placing the verticals at equal distances apart has been followed in many cases where three or more verticals were used. The use of the 1/6, 1/2, and 5/6 width, the centers of three parts of equal width, seems to have been made first by the U. S. Department of Agriculture in 1924 in Texas streams. In 1934 the Tennessee Valley Authority, in attempting to place their sampling on a more rational basis, selected visually the verticals to be sampled at the centers of widths representing equal discharge. A quantitative method of locating the verticals to represent equal discharges is presented in Section 14 of this report.

Forshey, in making observations at Carrollton in 1851, previously mentioned as the first to take more than one point in the vertical, sampled at the surface, mid-depth, and bottom, using the average of the three concentrations as the mean. The more accurate method of giving twice the weight to the mid-depth reading appears to be a recent development, the first record found being that of the U. S. Engineer Department sampling in the Mississippi in 1930. The following year Forshey used surface measurements at Carrollton and applied a coefficient of 1.2 to obtain the average sediment concentration. This is the earliest case found where such a coefficient was used. Taking samples at 0.6 depth without applying a coefficient has been a common practice since 1912 when it was apparently first used in rivers in Turkestan. A rational analysis for determining the position of sampling points in the vertical seems to have been made first by Straub, in 1929 and 1930, when he derived methods applicable to both straight-line and curvilinear sediment distributions. In the former case observations were made at 0.2 and 0.8 depth with weights of 5 and 3 applied, respectively. Another rational method was developed by Luby in 1937 which is applicable to any vertical distribution of sediment, but requires samples at a number of points in the vertical.

A depth-integrated sample seems to have been used first in 1874, when Cunningham made observations in the Ganges Canal in India, using a pipe which collected a column of water extending from the bottom of the stream to tho surface. Depth-integration, accomplished by means of a sampler moving between the surface and the bottom and taking in a part of the sample from each depth, seems to have been used first in 1897 by the U. S. Geological Survey in the Rio Grande River.

From the foregoing discussion it will be seen that a gradual development of the field practice of taking suspended sediment samples has taken place, from the simplest methods in the early years to the more complex but more accurate techniques in recent times. However, in this field the primitive methods have persisted along with the new to a larger extent than in most scientific fields, and cases of the earliest practices are still found in use at the present time. The newly developed theory of turbulence, as related to the sediment distribution in a stream, has apparently never been applied to the selection of sampling points. The turbulence theory appears to be the fundamental basis of the transportation of sediment, and, undoubtedly, marked progress in the knowledge of the subject will be made as the fundamental principles are applied to the solution of the problem of sediment transportation by streams.

III. LOCATION OF VERTICAL SAMPLING STATIONS

12. Transverse distribution of sediment--The number and locations of vertical sampling stations in a stream cross section are generally of less importance in a sampling program than either the location of sampling points in the individual verticals or the frequency of sampling. That the selection of verticals is not as important as the selection of sampling points in each vertical is readily evident upon study of the data presented in Tables 2 and 3. Table 3, and the discussion in Section 15, indicate that the sediment distribution in any stream can vary over a wide range from the surface to the bottom. On the other hand, the data in Table 2

TABLE 2

TRANSVERSE DISTRIBUTION OF SUSPENDED SEDIMENT IN VARIOUS RIVERS

River and location	Investigator and reference number	Date	Concentration in per cent of mean Per cent of width from one bank 20	25	40	50	60	75	80
Kuban, S.E. Russia	Gontcharoff (18,29)	----	90	--	95	98	106	--	110
Syr-Darya, Turkestan	Jakuschoff (29)	1912	--	113	127	--	106	85	--
Fyris, Sweden	Hjulstrom (22)	----	96	96	100	104	102	100	104
Black, Black Rock, Arkansas	M.R.C. (55)	1930-31	--	105	--	104	--	91	--
Arkansas, Tulsa, Oklahoma	" "	" "	--	94	--	102	--	104	--
Arkansas, Ozark Arkansas	" "	" "	--	102	--	102	--	95	--
Cimmarron, Guthrie, Oklahoma	" "	" "	--	98	--	97	--	104	--
Verdigris, Okay, Oklahoma	" "	" "	--	104	--	99	--	98	--
Grand, Waggoner, Oklahoma	" "	" "	--	111	--	98	--	92	--
South Canadian, Calvin, Oklahoma	" "	" "	--	99	--	109	--	92	--

show only a slight variation in sediment concentration across any given stream. Only one river, the Syra-Darya in Turkestan, showed a variation that probably would have affected the results appreciably if a sufficient number of verticals had not been used. However, due to the meager data presented, and the lack of correlation with velocity or discharge, the quantitative effects of the variations given are still unknown.

13. Methods used in locating vertical sampling stations--Determination of the number and locations of verticals to be sampled should be governed by the degree of accuracy required in the investigation, by the size, shape, and characteristics of the stream, and by the sediment load being carried at the time of sampling relative to the total yearly or other periodic load. Of these factors, the size of the stream and the accuracy desired are probably of greatest importance. The field technique used in any sediment investigation will naturally be dependent upon the relative importance of these factors. However, the basic criterion for a rational sampling technique is that the verticals should be located, or their mean concentrations weighted, with respect to the transverse distribution of stream discharge. That is, the verticals should either represent equal parts of the total water discharge or the value of mean concentration observed in each vertical should be weighted in proportion to the percentage of water discharge which it does represent.

The following methods of selecting the verticals, or locating the sampling points across a stream, have been used in several typical and important sediment investigations:

a. Single vertical at midstream.

b. Single vertical at thalweg or point of greatest depth.

c. Verticals at 1/4, 1/2 and 3/4 width.

d. Verticals at 1/6, 1/2, and 5/6 width.

e. Four or more verticals equally spaced across the stream.

f. Verticals at middles of sections of equal discharge.

Obviously, the simplest of the above practices is the selection of a single vertical at midstream or at the point of greatest depth. Of these two methods, the latter is preferable because, generally, the greatest percentage of discharge occurs at the point of maximum depth. However, the use of only one vertical should be limited to very small streams or to certain types of routine sampling.

Three verticals located at 1/4, 1/2, and 3/4 width in a stream cross section are widely used, a method which gives more information concerning the distribution of sediment and, naturally, a more accurate representation of sediment discharge than does a single vertical. This practice is popular, no doubt, because it is convenient and practicable to use in the field, particularly by unskilled resident observers.

Sampling verticals located at 1/6, 1/2, and 5/6 of the stream width have been used by a few investigators. This method of locating the verticals has, in theory, a rational justification when used in a wide stream, of uniform depth and uniformly distributed velocity, in which case the verticals are at the middles of three sections of equal discharge. However, the occurrence of such conditions of stream flow would be unusual; in most streams the choice of verticals at the quarter-points would be more reasonable. In general, the selection of verticals at 1/6, 1/2, and 5/6 width should be made only after their applicability to the stream to be sampled has been verified by determination of the velocity distribution and the shape of the cross section.

In important investigations it has been common practice to select a relatively large number of verticals at equal intervals across the stream. This method will give a good indication of the distribution of sediment across the stream, but it is rational only when the mean concentration for each vertical is weighted with respect to the stream discharge in the section represented by the vertical. Unless the results are weighted in this manner they will be unreliable as an indication of the total quantity of sediment carried by the stream.

The selection of verticals so that each represents an equal portion of stream discharge is another rational practice. In the field, however, this method is usually only approximated. The sections of equal discharge are determined by visual inspection, substantiated, in some cases, by previous discharge measurements, and the verticals are located at their middles. This general method has a rational basis but the accuracy of its application depends largely upon the judgment of the observer in dividing the stream cross section.

In small streams, and in larger streams where long-period routine investigations are being made, a direct application of the method of selecting verticals so that all of them represent equal quantities of discharge, can be simplified somewhat. If only one vertical is to be sampled it should be selected so as to represent the greatest portion of the stream discharge. If two verticals are used the cross section should be divided into two areas of equal discharge with the vertical to be sampled located, not at the center of the area, but rather at the imaginary line dividing it again into two smaller areas of equal discharge. The location of three or more verticals would be done in a similar manner. When the number of verticals becomes large relative to the width of the stream, the approximations introduce negligible error and each area can be sampled at its exact middle.

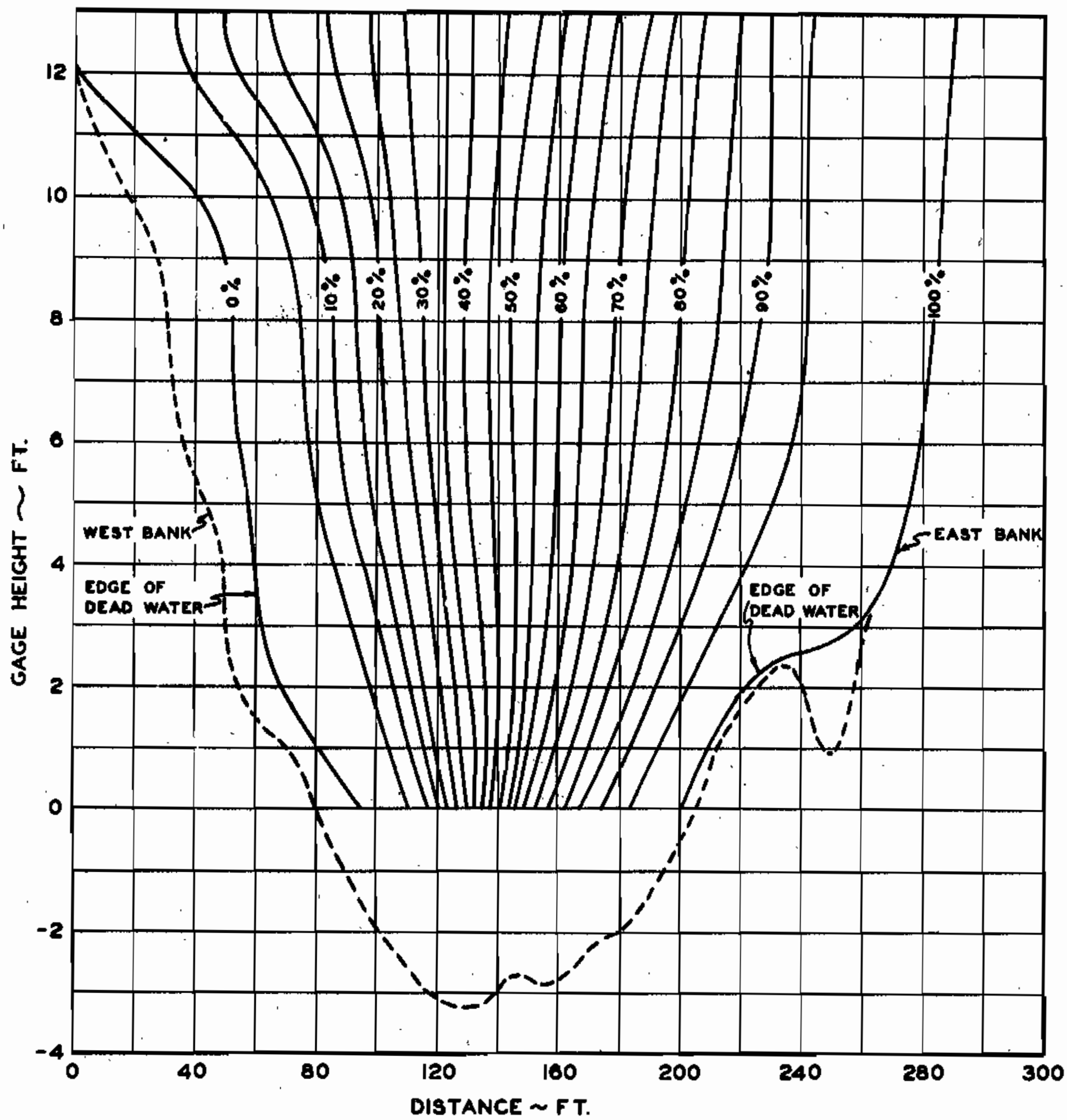
The application of either of these rational methods; namely, equally spaced verticals with concentrations weighted according to discharge, or verticals spaced so that they represent equal parts of the discharge, requires a knowledge of the distribution of discharge in the stream cross section at the sampling station. The results obtained with verticals located at the middles of sections of equal discharge are, probably, more reliable and accurate than those obtained from the weighted concentrations observed at equally spaced verticals. However, the value of the results, in any case, depends upon the thoroughness and accuracy of previous investigations. The selections of one or the other of these two rational practices for any particular location should be based upon the indications of previous data, the characteristics of the stream, the type of observer, and the type of investigation under consideration.

14. Lane method of selecting vertical sampling stations--A practical application of the rational method of selecting verticals that will represent equal portions of stream discharge has been developed by Professor E. W. Lane of the Iowa Institute of Hydraulic Research. Based on the principle of the Luby method for selecting sampling points in the vertical, this method allows an accurate determination of the location of the verticals so that each will represent an equal portion of discharge when reliable data concerning the distribution of the discharge at the sampling section, for all stages of the stream, are available.

The Lane method of selecting verticals has been developed for the cableway measuring section in the Iowa River at Iowa City, a stream gaging station operated regularly by the U. S. Geological Survey. Fig. 1 shows the discharge distribution across the section for varying stages and the cumulative discharge up to any point in per cent of the total discharge. The curves were constructed by plotting data from individual discharge measurements as shown in Fig. 2. Starting at the water's edge, the cumulative discharge to any point, in per cent of the total discharge for the measurement, was plotted with respect to gage height and distance to the point. The plotted points were connected by a smooth curve. The distances to points of equal increments of discharge, that is, 5, 10, 15 per cent, etc., were determined by graphical interpolation and plotted with respect to per cent of discharge as shown in Fig. 1. This process was repeated for a sufficient number of discharge measurements to cover the desired range in stage. Smooth curves or contours representing percentages of discharge for all stages were then constructed.

In Fig. 3 the percentages of discharge are plotted as ordinates and the distances to points of observation as abscissas for various stages of the river. These curves may also be plotted by interpolation of the data given in Fig. 2.

The verticals to be sampled can be located by using the data shown in Table 5 and either Fig. 1 or Fig. 3. Assuming the stage to be 4.0 ft. and that samples are desired from six verticals, Table 5 indicates that the mean discharges for six sampling points are 8, 25, 42, 58, 75, and 92 per cent. Referring to the curves for these percentages and a gage height of 4.0 ft. in Fig. 1 or Fig. 3, the distances from the reference station at



NOTE:-

PERCENTAGES INDICATE CUMULATIVE DISCHARGE TO ANY POINT IN PER CENT OF THE TOTAL DISCHARGE.

IOWA RIVER, IOWA CITY, IOWA

DISCHARGE DISTRIBUTION

VARIATION WITH PER CENT OF FLOW

U. S. GEOLOGICAL SURVEY IOWA CITY, IA.

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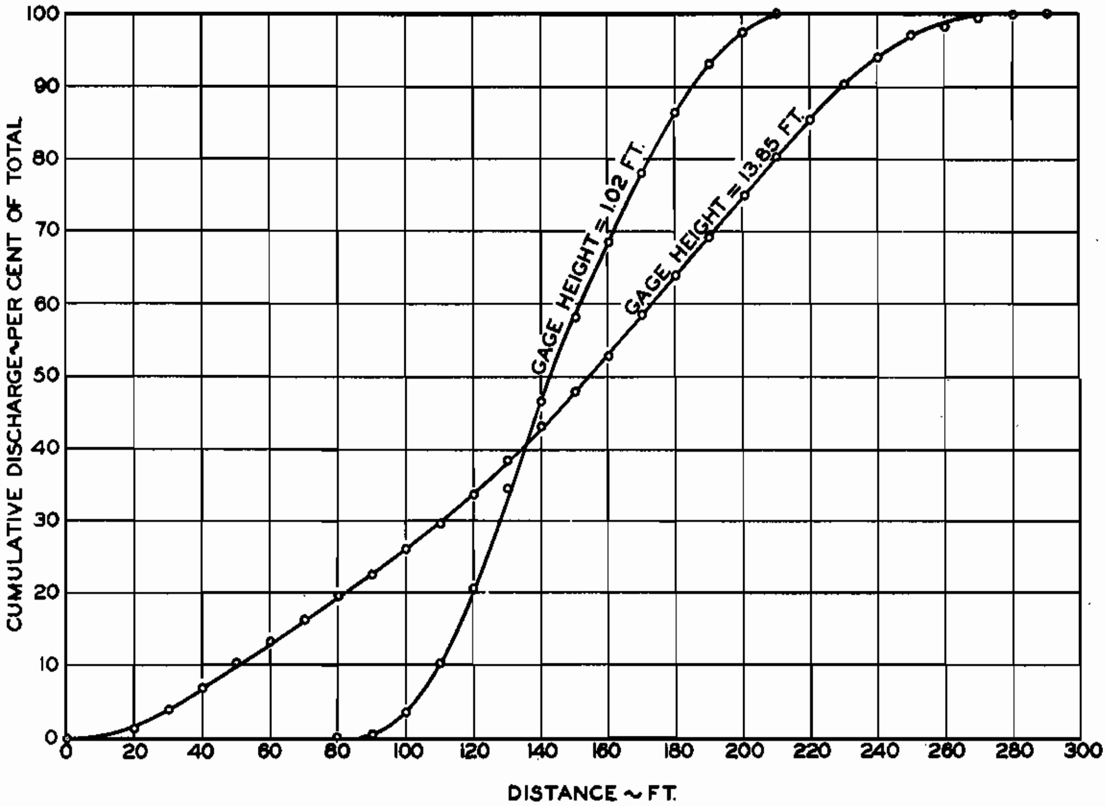

IOWA RIVER, IOWA CITY, IOWA

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INDIVIDUAL MEASUREMENTS

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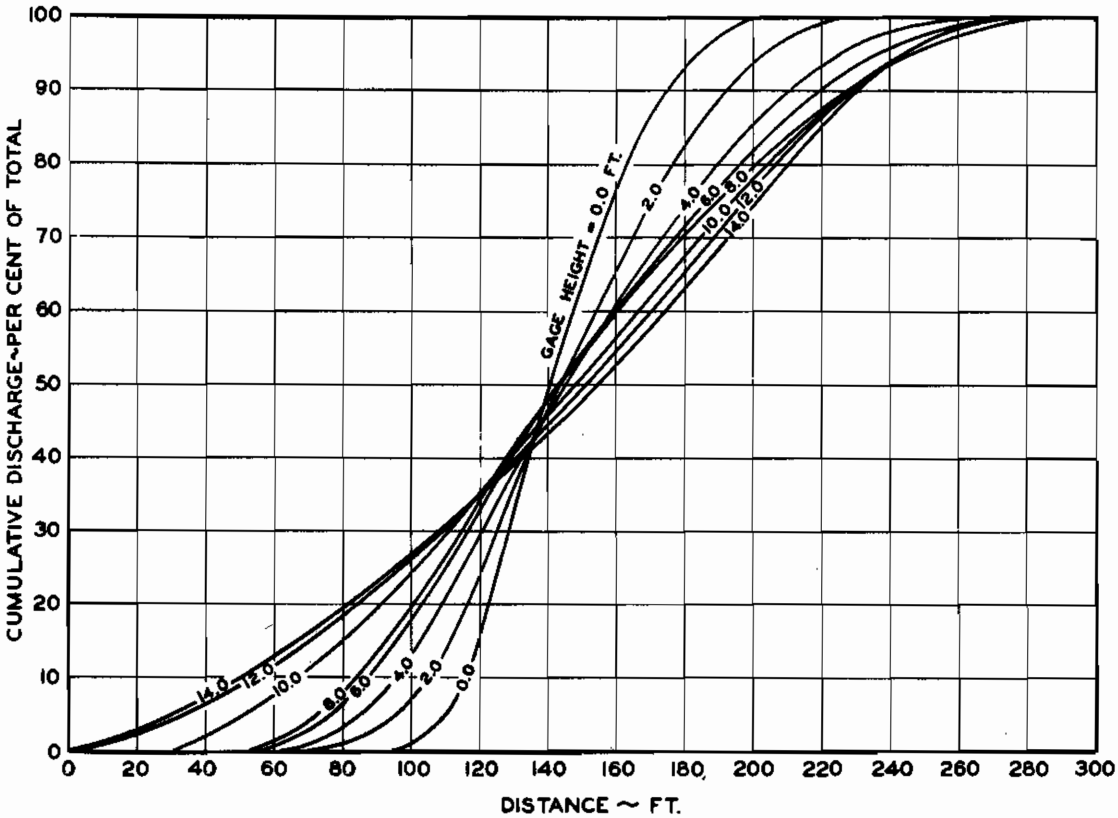

IOWA RIVER, IOWA CITY, IOWA

DISCHARGE DISTRIBUTION

VARIATION WITH GAGE HEIGHT

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which samples should be taken are found to be 92, 114, 134, 157, 180, and 215 ft., respectively.

This method is readily applicable to gaging stations at which sediment samples and discharge measurements are taken regularly. The curves, which may be constructed from previous discharge measurements, can be used in the field to locate the sampling points. Determination of the river stage is the only other observation that is necessary. The curves may need adjustment if major changes in the river cross section take place. However, with only minor changes they will remain accurate within reasonable limits.

If samples which are representative of the sediment distribution in the vertical are taken at points spaced transversely by the method described, they will be representative of equal discharges. Furthermore, if the samples in the verticals are of equal volume, they may be combined to form a composite sample which will give the mean sediment concentration for the total water discharge. If either the Luby or the depth-integration method is used for selecting sampling points in the verticals and the same number of equal volume samples are taken in each vertical, all the samples in the cross section may be combined to form a composite sample which will be representative, not only of the average sediment concentration, but also of the average size distribution of the sediment load.

IV. SELECTION OF SAMPLING POINTS IN A VERTICAL

15. Sediment distribution in a vertical--The variation of sediment concentration from the surface to the bottom of a stream is, in general, considerably greater than that across the stream, as was pointed out in Section 12 and shown by Tables 2 and 3. The latter table gives the ratios of sediment concentrations at mid-depth and at the bottom, to that at the surface, as determined in a large number of investigations. Each ratio represents the mean value of a number of observations. The extreme ratios for each series of data are given to show the variation at a single location. In most cases the concentration was found to be higher at mid-depth than at the surface, and also higher at the bottom than at mid-depth, indicating an increase in concentration with depth. This was indicated also by the results obtained from samples taken at 0.2, 0.4, 0.6, and 0.8 depths and at 1 ft. above the bed, as shown near the bottom of the table. Most of the ratios of mid-depth to surface concentration fall between 1.0 and 1.4, and of bottom to surface concentration, between 1.1 and 1.5. The limiting ratios given in the table represent the highest and lowest ratios observed in any vertical at that location for any single set of surface, mid-depth, and bottom readings. The spread of these ratios at all stations indicates a wide variation of the sediment content at any point from that of the mean for the stream. Some of the extreme variations in sediment distribution indicated in the table are probably due to errors in sampling, analysis, or computation, and no means is available for determining to what extent the variations are due to errors and to what extent to momentary fluctuation in concentration. It is believed, however, that the latter is a very important factor. In order to indicate

TABLE 3

DATA FROM PREVIOUS INVESTIGATIONS ON VERTICAL DISTRIBUTION OF SUSPENDED SEDIMENT

River and Location	Investigator and Reference	Date	Average Discharge c.f.s.	Number of observations in series	Ratio of Sediment Concentration at Point Noted to Concentration at Surface: Mean Ratio, Mid-depth	Mean Ratio, Bottom	Limits of Ratios, Mid-depth	Limits of Ratios, Bottom	Standard Deviation, Mid-depth	Standard Deviation, Bottom
Mississippi, South Pass	Talcott (54)	1838	—	—	—	1.51	—	—	—	—
Elbe, Harburg, Germany	Blohm (4)	1837-54	—	—	.94	.98	—	—	—	—
Rhone, France	Surell (20,26)	1844	—	—	—	1.88	—	—	—	—
Garonne, Marmande, France	Baumgarten (3)	1847	—	—	1.41	1.25	—	—	—	—
Mississippi, Carrollton, La.	Forshey (26)	1851-52	—	—	1.24	1.30	—	—	—	—
Mississippi, St. Louis, Mo.	McMath (36)	1879	—	—	1.09	1.15	—	—	—	—
Mississippi, Helena, Ark.	U.S.E.D. (42)	1879	—	—	—	1.58	—	—	—	—
Sacramento, Kerschevals	LeConte (42)	1879	—	—	1.63	1.01	—	—	—	—
Mississippi, Columbus, Ky.	U.S.E.D. (54)	1879	—	79	1.72	2.33	—	—	—	—
Mississippi, Hampton Landing, Ark.	U.S.E.D. (54)	1879	—	990	1.10	1.14	—	—	—	—
Mississippi, Kings Point, Miss.	U.S.E.D. (54)	1879	—	—	1.07	1.11	—	—	—	—
Arkansas, Pine Bluff, Ark.	U.S.E.D. (54)	1879	—	135	1.13	1.60	—	—	—	—
Missouri, St. Charles, Mo.	U.S.E.D. (44)	1879	—	—	1.02	1.05	—	—	—	—
Mississippi, Fulton (low stages)	U.S.E.D. (54)	1879-80	—	59	1.66	1.75	—	—	—	—
(medium stages)	U.S.E.D. (54)	1879-80	—	64	1.27	1.25	—	—	—	—
(high stages)	U.S.E.D. (54)	1879-80	—	55	1.12	1.15	—	—	—	—
Mississippi, Carrollton, La.	U.S.E.D. (43)	1879-80	—	—	1.44	1.83	—	—	—	—
Mississippi, Winona, Minn.	U.S.E.D. (43)	1880-81	—	—	.94	1.06	—	—	—	—
Mississippi, Prescott, Wis.	U.S.E.D. (43)	1880-81	—	—	1.28	1.29	—	—	—	—
Mississippi, Clayton, Iowa	U.S.E.D. (43)	1880-81	—	—	1.05	1.03	—	—	—	—
Mississippi, Hannibal, Mo.	U.S.E.D. (43)	1880-81	—	—	1.24	1.36	—	—	—	—
Mississippi, Grafton, Ill.	U.S.E.D. (43)	1880-81	—	—	1.01	1.07	—	—	—	—
Mississippi, St. Louis, Mo.	U.S.E.D. (43)	1880-81	—	—	1.32	1.45	—	—	—	—
Bhagiratti, Bengal, India	Livesay (7)	1893	—	5	1.52	2.24	1.27-1.71	1.84- 2.49	—	—
Sutlej, Punjab, India	Buckley (7)	1894-97	—	6	1.19	1.62	1.05-1.36	1.15- 2.02	—	—
Colorado, Yuma, Ariz.	Grunsky (19)	1909-16	—	1165	1.04	1.12	—	—	—	—
Colorado, Yuma, Ariz.	Grunsky (19)	1917-27	—	1841	1.06	1.15	—	—	—	—
Irrawaddy, Saiktha, Burma	Saunderson (7)	1914	1,370,000	10	.96	1.12	.73-1.37	.64- 2.42	—	—
Irrawaddy, Donabyu, Burma	Saunderson (7)	1914	1,095,000	13	1.07	1.24	.54-1.55	.66- 1.92	—	—
Colorado, Topock, Ariz.	Howard (24)	1925-28	—	62*	—	.79	—	—	—	—
Mississippi, Grafton, Ill.	Mississippi River Commission (55)	1930-31	39,100	35	1.16	1.24	.74-2.42	.83- 2.37	0.33	0.33

Mississippi, Helena, Ark.	M.R.C. (55)	1930-31	154,000	77	1.11	1.15	.57-1.64	.82- 1.81	.15	.18
Mississippi, Chicot Landing, Ark.	M.R.C. (55)	1930-31	147,000	76	1.29	1.40	.78-2.90	.99- 2.98	.33	.41
Mississippi, Vicksburg, Miss.	M.R.C. (55)	1930-31	149,000	60	1.20	1.23	.66-1.83	.90- 1.94	.20	.20
Mississippi, Red River Landing, La.	M.R.C. (55)	1930-31	194,000	61	1.06	1.08	.89-1.33	.93- 1.80	.09	.14
Mississippi, Carrollton, La. **	M.R.C. (55)	1930-31	190,000	63	1.37	4.42	.14-7.14	.35-30.5	1.03	5.95
Missouri, St. Charles, Mo.	M.R.C. (55)	1930-31	36,500	40	1.20	1.28	.95-4.87	.95- 4.75	.61	.66
Ohio, Mound City, Ill.	M.R.C. (55)	1930-31	70,900	51	1.20	1.42	.59-3.68	.86- 5.08	.43	.71
Atchafalaya, Simmesport, La.	M.R.C. (55)	1930-31	37,000	58	1.10	1.21	.71-2.41	.71- 2.84	.25	.31
White, Devalls Bluff, Ark.	M.R.C. (55)	1930-31	31,000	36	1.05	1.23	.71-1.36	.89- 1.92	.15	.23
Black, Black Rock, Ark.	M.R.C. (55)	1930-31	8,300	57	1.03	1.25	.74-1.77	.73- 2.43	.15	.36
Arkansas, Ozark, Ark.	M.R.C. (55)	1930-31	21,900	91	1.13	1.24	.22-1.65	.29- 2.18	.22	.30
Verdigris, Okay, Okla.	M.R.C. (55)	1930-31	2,820	28	1.01	1.04	.79-1.25	.77- 1.34	.34	.45
Old, near Torras, La.	M.R.C. (55)	1930-31	—	54	1.15	1.33	.70-2.25	.86- 2.69	.23	.46
Grand, Waggoner, Okla.	M.R.C. (55)	1930-31	6,610	35	1.00	1.13	.50-1.98	.27- 2.72	.27	.47
South Canadian, Calvin, Okla.	M.R.C. (55)	1930-31	835	21	1.27	1.29	.90-3.50	.87- 2.34	.53	.38
Yazoo, Greenwood, Miss.	M.R.C. (55)	1930-31	5,270	111	1.06	1.06	.42-2.64	.49- 2.23	.31	.31
Ouchita, Monroe, La.	M.R.C. (55)	1930-31	1,210	167	1.01	1.06	.37-1.60	.23- 4.04	.21	.38
Cimmarron, Guthrie, Okla.	M.R.C. (55)	1930-31	2,220	9	1.02	1.05	.94-1.10	.83- 1.15	.05	.09
Red, Denison, Texas	M.R.C. (55)	1930-31	3,800	149	1.11	1.22	.60-2.14	.71- 2.74	.22	.34
Red, Index, Ark.	M.R.C. (55)	1930-31	—	131	1.15	1.29	.77-3.16	.59- 4.48	.32	.50
Red, Alexandria, La.	M.R.C. (55)	1930-31	22,850	145	1.21	1.34	.76-2.31	.75- 4.59	.19	.41
Washita, Durwood, Okla.	M.R.C. (55)	1930-31	1,030	106	1.05	1.12	.69-2.09	.71- 3.22	.20	.30
Little, Idabel, Ark.	M.R.C. (55)	1930-31	708	20	1.00	.99	.38-1.75	.41- 1.89	.34	.36
Little, Horatio, Ark.	M.R.C. (55)	1930-31	3,330	84	1.09	1.20	.29-5.05	.29- 4.29	.71	.74
Little, Wilton, Ark.	M.R.C. (55)	1930-31	334	17	.97	1.12	.58-3.13	.52- 4.34	.58	.82
Sulphur, Darden, Texas	M.R.C. (55)	1930-31	1,334	75	1.07	1.24	.41-2.21	.42- 3.67	.27	.53
					Ratio of sediment concentration at various depths to concentration at surface					
					0.2d	0.4d	0.6d	0.8d	1 ft. above bottom	
Murghab, Afghanistan	Gluschkoff (16,29)	1909	—	—	1.04	—	1.30	1.59	2.04	
Kuban, S.E. Russia	Gontscharoff (18,29)	1925	—	—	1.10	1.17	1.20	1.25	1.35	
Volga, Astrachan, Russia	Appoloff and Lukaschin (1,29)	—	—	—	1.01	1.01	1.00	0.98	1.05	
Fyris, Sweden	Hjulstrom (22)	—	—	8	1.02	1.07	1.14	1.20	1.22	
Brazos, Rosenberg, Texas	Faris (12)	1929	—	10	1.05	1.06	1.06	1.12	1.20	
——— Punjab, India	Taylor (51)	—	—	—	1.20	1.24	1.36	1.50	—	
——— Punjab, India	Taylor (51)	—	—	—	1.23	1.27	1.34	1.48	—	

*(Partial data).
**(The data in this series are very erratic).

the variability of values better than is possible by a comparison of the extremes, where enough data was available, the standard deviation was computed. From the data shown in Table 3 it is evident that, if accuracy is to be attained in determining the sediment discharge of a stream, consideration must be given to the vertical distribution of the sediment and the sampling points in the verticals must be selected on a scientific basis.

16. Methods of selecting sampling points in a vertical--The purpose of sampling at more than one point in a vertical is usually to secure samples from which to determine the magnitude of the sediment load carried in a unit width of the stream in a unit of time, and, in some cases, to determine the particle size composition. As previously shown, the sediment concentration usually increases from the surface to the bottom of a stream. It is well known also that the velocity in a vertical decreases from the surface to the bottom and, consequently, more water passes through a unit area of cross section near the surface than at the bottom. Any scientific method of sampling must take into account both the variation of sediment concentration and the variation in velocity at a vertical which is to be sampled.

Recent studies of turbulence in flowing water have thrown a great deal of light on the vertical distribution of sediment in streams. The turbulence theory indicates that there is a tendency for sediment of all sizes to be more concentrated near the bottom of a stream than at the surface. In the case of the very fine particle sizes, this variation is slight, but for the larger sizes the variation is considerable. A linear distribution may be assumed for the small sizes with sufficient accuracy, but the distribution of coarser material is a variable function of the depth, the concentration increasing rapidly as the bottom is approached.

Variations in the vertical distribution of sediment have been taken into account in certain investigations in either of the following ways:

<u>a</u>. by taking samples at enough points to establish the vertical variation with the required degree of accuracy,

<u>b</u>. by applying correction factors, based on previous observations, to samples taken at definite locations, and

<u>c</u>. by taking samples which integrate the concentration throughout the depth.

Velocity variations in the vertical have been given proper weight either by taking samples representing equal volumes of discharge or by taking samples representing known volumes of discharge.

The accuracy of the methods used in investigations in the past has varied greatly. In some cases the procedure was based on a thorough consideration of the principles involved, while in other cases the methods were selected in a manner quite arbitrary, generally with a view to convenience in sampling or to simplifying the rules necessary to secure uniformity of practice.

In the following discussion the different methods used have been classified as arbitrary, empirical, or rational. The arbitrary methods are those in which fixed points in the verticals are chosen for sampling, generally on account of greater convenience. Empirical methods are those where the points chosen, or the coefficients applied, are based on previous, more exact measurements. Rational methods are those which are based upon an analysis of the principles involved, usually using simplifying assumptions. It is not possible to draw up a rigid classification as there are many border line cases.

17. <u>Arbitrary and empirical methods</u>--In past investigations the sampling points in a vertical have been selected arbitrarily, in general, for convenience, and because less training on the part of the observer was required. The arbitrary or empirical sampling methods which have been in most common use are described briefly as follows:

<u>a</u>. a single sample taken at the surface with or without coefficient applied,

<u>b</u>. a single sample taken at 0.6 depth,

<u>c</u>. samples taken at the surface and bottom with equal weights applied to the concentration observed,

<u>d</u>. samples taken at the surface, mid-depth, and bottom, with equal weights applied, and

<u>e</u>. samples taken at surface, mid-depth, and bottom with weights of 1, 2, and 1, respectively, applied.

The advantages of the single surface sample method are, obviously, its simplicity and its suitability for use by unskilled observers. However, in order to make this an empirical method, it will first be necessary to obtain considerable data on the sediment load carried by the stream from which to derive the coefficients. Even then, total concentrations based upon these coefficients would be questionable. For size analysis this is the least dependable of all methods, since the larger particles are generally not present near the surface of a stream.

The method which involves taking only one sample in the vertical at 0.6 depth has been found satisfactory in rivers of Texas, India, and Turkestan. It cannot necessarily be considered reliable or accurate for determining either total concentration or particle size, but it is undoubtedly better than if only surface samples are taken. A practical disadvantage is that sampling at a fractional depth may present difficulties to an unskilled observer.

Recent studies of turbulence and sediment distribution have demonstrated that the distance from the bottom of a stream to the point of average sediment concentration in a vertical varies inversely with the size of the suspended material. Therefore, it cannot be assumed that a given proportion of the depth will give the average concentration in all streams, and, in many cases, not even at a single station in an individual stream, since the size of sediment carried may differ at that station from time to time.

The method which involves taking two samples in each vertical, at the surface and bottom, has a practical advantage in being suitable to unskilled observers. When the two samples are given equal weight in the average sediment determination, this method is considered inaccurate for evaluating either total concentration of sediment or particle size. It is strictly an arbitrary method, without empirical or rational justification.

Sampling at the surface, mid-depth and bottom, using equal weights at the three points, is an arbitrary method but one that has been used extensively. The accuracy of this method has been studied by Dr. L. G. Straub and his findings are discussed in Section 19. This "three-point" method is undoubtedly more accurate than surface or surface and bottom sampling. In recent years it has become common practice to give double weight to the concentration indicated by the mid-depth sample. This practice is based on the assumption that the average of the surface and mid-depth samples represents the upper half of the discharge in the vertical and the average of the mid-depth and bottom samples represents the lower half. A number of observers have found that weights of 1, 2, and 1 are approximately proportional to the rate of water discharge in the respective sections of the vertical. For example, it was found from many measurements in the Mississippi River (55) that the upper 1/4, middle 1/2, and bottom 1/4 of a vertical carried 27.2, 51.2, and 21.6 per cent of the water discharge, respectively. Sampling at surface, mid-depth, and bottom is a relatively simple method to use, and can be performed fairly easily by dependable, although inexperienced, observers.

18. The precise method--The precise method of sampling in a vertical involves collection of a relatively large number of point sediment samples simultaneously with velocity measurements. Sufficient data are collected to construct accurate vertical velocity and sediment distribution curves, the corresponding abscissas of which are multiplied to obtain a sediment-velocity curve. The area under this curve represents the sediment discharge in the vertical. This method has been used considerably in sampling for research purposes, but it is too laborious for routine sampling.

19. The Straub method--Probably the most complete analytical and experimental work pertaining to the selection of sampling points was that performed by Dr. L. G. Straub (50) of the U. S. Engineer Department, Missouri River Division, during 1929 and 1930, relative to obtaining samples from the Missouri River and its tributaries. The method developed from these studies was the only one found in which the coefficients applied were based on mathematical derivation, and, therefore, a brief summary of the theory of this method will be given. More complete details of this method will be found in reference No. 50 of the bibliography.

By means of a logarithmic plot of a typical velocity curve, an empirical exponential equation was derived that would define the general shape of such a curve. This equation was of the form

$$v = v_s h^m$$

where v = velocity at any point

v_s = velocity at the surface

h = distance above zero of coordinates relative to the total depth (zero was slightly below the stream bed).

m = exponent dependent upon the shape of the velocity curve, (found to be 0.284 in the Missouri River).

Based upon the typical velocity curve, the discharge, q, per unit width of stream could be expressed by

$$q = 0.793\ v_s$$

For most of the Missouri River stations at which samples were taken, an approximate straight-line variation of sediment concentration from the water surface to the stream bed was found to exist. For such cases, the following equation for sediment distribution applies:

$$s = s_o - (s_o - s_s)h$$

where s = sediment concentration at any point; h = distance above zero

s_o = sediment concentration at $h = o$

s_s = sediment concentration at surface

Since the sediment discharge at any point is the product of the water velocity and sediment concentration at the point, these two equations were multiplied and the result integrated throughout the stream depth to give an expression denoting sediment discharge, S, per unit width of stream:

$$S = v_s(0.335\ s_o + 0.458\ s_s)$$

Then, to determine the factor by which the water discharge must be multiplied to obtain the sediment discharge, the equation for sediment discharge per unit width of stream was divided by the equation for water discharge per unit width of stream. This provided a general expression with the coefficient to be applied to the sediment concentrations obtained at the zero point for vertical coordinates and at the surface:

$$S/q = 0.422\ s_o + 0.578\ s_s$$

Since the sediment concentration had a straight-line variation, the concentration at the surface or at the bottom could be expressed in terms of concentration at any other two points in the vertical. The points of 0.2 and 0.8 depth were chosen and values for concentrations at these points in relation to bottom and surface concentration were substituted in the general expression. It was found that coefficients of 0.385 and 0.615 should be applied to the 0.8 and 0.2 depth points, respectively. The final expression for the approximate silt discharge per unit width of stream is

$$S = (3/8\ s_{.8d} + 5/8\ s_{.2d})\ q$$

where S = the total sediment discharge per unit width,

$s_{.8d}$ = sediment concentration at 0.8 depth,

$s_{.2d}$ = sediment concentration at 0.2 depth,

and q = the water discharge per unit width.

This expression will be referred to as the Straub "two-point" method.

Dr. Straub recognized that in certain instances the sediment concentration increases rapidly toward the bottom and that erroneous values would be secured if the coefficients developed for a straight-line variation were used. For the Missouri River he found the general equation for curvilinear sediment distribution to be

$$s = k^n s_s h^{-n},$$

the value of $\underline{k}$ depending upon the center of coordinates.

With a derivation similar to that used for the straight-line variation he arrived at the equation.

$$S = K\, s_s\, q$$

The value, K, which was termed the "silt distribution factor", although found to vary within rather narrow limits, is a complicated expression. The exponents m and n in the velocity and sediment distribution curves respectively, are unknowns in the expression and, consequently, if they were determined it would only be necessary to obtain a surface sample to determine sediment discharge.

A "three-point" method, with an arithmetic average of concentrations in samples secured at surface, mid-depth, and bottom, has been used in other investigations than in the Missouri River. A comparison was made of this method and the "two-point" method with the theoretically correct value of sediment discharge for both straight-line and curvilinear sediment distribution which is presented in Table 4. The per cent deviation from the theoretically correct value for various ratios of sediment concentration at surface to that at bottom, and for various exponents of the silt distribution curve are shown. The analysis shows clearly the inaccuracy of the "three-point" method when compared with the theoretical and "two-point" methods for both straight-line and curvilinear variation of sediment distribution. Also, as the concentration at the surface decreases in relation to that at the bottom the per cent deviation from the theoretical increases rapidly for both methods. It is obvious that the "three-point" method is more limited in use than the "two-point" method. The values in the table also show that if the assumed values of m and n are reasonably correct, the "two-point" method will be quite accurate when a curvilinear variation exists. The "three-point" method gives values that are always greater than the theoretical, while the values given by the "two-point" method are slightly lower.

TABLE 4

THEORETICAL COMPARISON OF METHODS OF OBTAINING SEDIMENT DISCHARGE

(a) Straight-line Variation of Sediment Distribution

Ratio of concentration, surface to bottom s_s/s_b	Per cent deviation from theoretical value	
	"two-point" method	"three-point" method
0.2	- 0.88	+ 10.11
0.3	- .70	+ 8.55
0.4	- .55	+ 6.29
0.5	- .42	+ 4.82
0.6	- .31	+ 3.58
0.7	- .22	+ 2.35
0.8	- .14	+ 1.56
0.9	- .06	+ 0.74
1.0	0	0

(b) Curvilinear Variation of Sediment Distribution

Exponent *n* in sediment distribution equation	s_s/s_b	Per cent deviation from theoretical value	
		"two-point" method	"three-point" method
0.40	0.209	- 3.40	+ 69.0
.30	.3095	- 1.88	+ 41.9
.20	.456	- 0.85	+ 22.95
.15	.553	- .71	+ 16.04
.0875	.711	- .47	+ 8.15
.050	.823	- .19	+ 4.43
0	1.000	0	0

In the early stages of the Missouri River investigation of 1929-30, accurate sediment discharges were obtained by securing samples and velocity measurements at 1 ft. below the surface, at 0.2, 0.5, and 0.8 depth, and 1 ft. above the bottom. The sediment discharge was computed using the precise method. This study included 27 days between May 8 and August 20,

1929. Sediment discharges were also computed by the "two-point" and "three-point" methods described previously and the results compared with those obtained by the precise method. For the "two-point" method the deviation from the precise varied from +6.54 to -11.8 per cent, the algebraic average being only -0.37 per cent. In the "three-point" method the algebraic average was not appreciably greater, being +0.56 per cent, but the variations were considerably greater, ranging from +11.3 to -13.6 per cent. Dr. Straub pointed out that this close agreement was probably due to two factors; first, samples not being taken very close to the stream bed or directly at the surface, and second, that there was generally only 10 to 20 per cent more sediment per unit volume in bottom samples than in those at the surface. In this and other investigations, the "three-point" method tended to give results higher than the precise, while the "two-point" method gave results slightly lower. This observation is also borne out in the theoretical comparisons in Table 4.

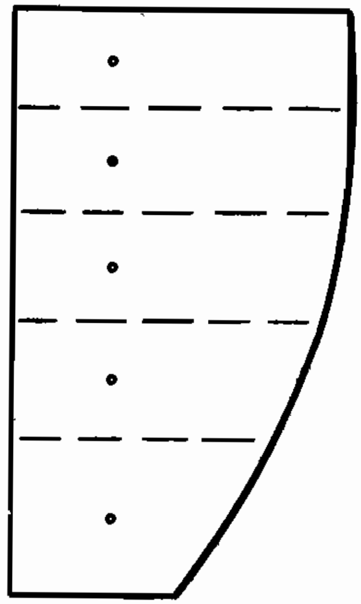
Since precise, preliminary investigations established the reliability and accuracy of the "two-point" method for use in the Missouri River, it was used extensively for investigations in that river. This method is applicable for obtaining sediment concentration regardless of the distribution as long as it is approximately a straight line and the velocity distribution is consistently about the same. This method is not in all cases satisfactory for obtaining a representation of the particle size since the vertical distribution curves for large sizes generally have considerable curvature near the stream bed.

20. <u>The Luby method</u>--Mr. J. P. Luby of the St. Paul U. S. Engineer District developed a rational method for selecting points in the vertical

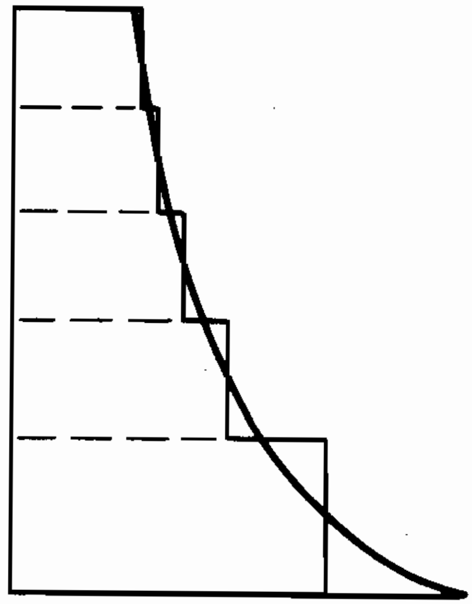
which has been used recently by some of the other U. S. Engineer Districts. In this method the area under the vertical velocity curve is divided into equal areas as shown in Fig. 4(a). If samples are taken at the centroids of these areas they will be representative of equal portions of the discharge. The samples, if of equal volume, can then be combined and the composite will be representative of the mean sediment concentration in the vertical. The mean particle size composition will also be represented in the composite sample, providing enough points are chosen. The number of points to sample will largely be determined by the curvature of the sediment distribution graph, the shape of the vertical velocity curve, and the depth of the stream.

Fig. 4(b) shows a typical sediment distribution curve with divisions and locations of sampling points as indicated by the division of the vertical velocity curve. This illustrates the approximations in the Luby method; namely, in assuming the sediment concentration at the centroid to be the mean of the area. As seen by this curve the actual mean in each area will be at a point below the centroid except near the surface, and in all cases the Luby method will tend to show concentrations which are smaller than actually exist. As the curvature of the sediment distribution graph increases, the tendency for error increases, requiring division into a greater number of equal areas of discharge to secure the same degree of accuracy.

Curve A of Fig. 5 is a typical vertical velocity curve obtained by the U. S. Geological Survey (40) from 78 measurements in seven rivers of southern New York during 1901. Curve B, plotted from the data of Curve A, shows the per cent of discharge below any given per cent of depth. Having



(a) Vertical velocity curve and spacing of sampling points to represent equal portions of discharge.

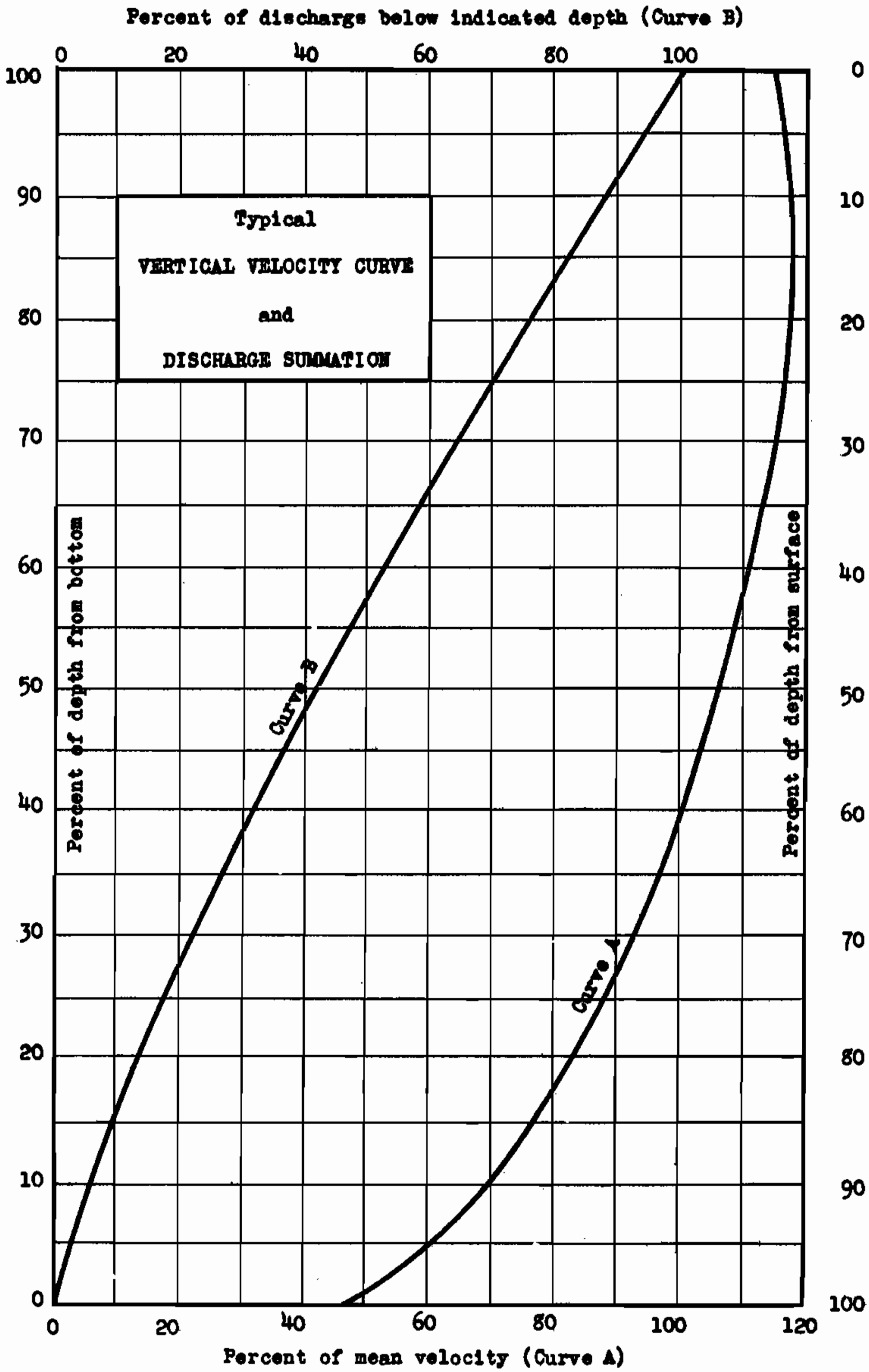


(b) Sediment distribution curve.

Fig. 4—Illustration of the Luby method.

these curves for any stream, the location of sampling points by the Luby method is easily made. After establishing the number of points desired, their percentages are found from Table 5 and by entering Curve B at the middle of each equal fraction of the discharge, the per cent of depth for each point is determined. Thus, if four points were desired, from Table 5 the middles of the equal fractions of discharge would be 12, 38, 62, and 88 per cent. From Curve B, the corresponding sampling points would be 18, 45, 68, and 90 per cent of the depth above the bottom of the stream.

Table 5 facilitates determination of the location of the centroids of the sections of equal discharge. The table is entered at the number of sampling points desired, giving the cumulative percentage of water discharge to the centroid of each section.


Percent of discharge below indicated depth (Curve B)
0
20
40
60
80
100
Typical
VERTICAL VELOCITY CURVE
and
DISCHARGE SUMMATION
Curve B
Curve A
Percent of depth from bottom
100
90
80
70
60
50
40
30
20
10
0
Percent of depth from surface
0
10
20
30
40
50
60
70
80
90
100
0
20
40
60
80
100
120
Percent of mean velocity (Curve A)

The Luby method is applicable to a wide range of field conditions and, if properly conducted, can be expected to give good results for both total sediment concentration and particle size distribution.

TABLE 5

CUMULATIVE PERCENTAGES OF TOTAL DISCHARGE AT CENTROID OF SECTIONS OF EQUAL DISCHARGE FOR A GIVEN NUMBER OF SAMPLING POINTS

No. of sampling points	Mid-percentage for each section														
2	25	75													
3	17	50	83												
4	12	38	62	88											
5	10	30	50	70	90										
6	8	25	42	58	75	92									
7	7	21	36	50	64	79	93								
8	6	19	31	44	56	69	81	94							
9	6	17	28	39	50	61	72	83	94						
10	5	15	25	35	45	55	65	75	85	95					
11	5	14	23	32	41	50	59	68	77	86	95				
12	4	12	21	29	38	46	54	62	71	79	88	96			
13	4	12	19	27	35	42	50	58	65	73	81	88	96		
14	4	11	18	25	32	39	46	54	61	68	75	82	89	96	
15	3	10	17	23	30	37	43	50	57	63	70	77	83	90	97

21. <u>The depth-integration method</u>--The depth-integration method of sampling suspended sediment in streams presupposes that the sampler fills at a rate proportional to the velocity of the approaching flow and that, in traversing the depth of a stream at a uniform speed, the sampler will receive at every point in the vertical a small instantaneous specimen of the water-sediment mixture, the volume of which is proportional to the instantaneous velocity. The available records indicate that this method of sampling was first used by Major Allan Cunningham in the Ganges Canal, India, in 1874. He lowered a tube from the surface to the bottom and

collected a column of water the full depth of the canal.

The main factors which influence the rate of filling of a sampler are the stream velocity and the hydrostatic pressure at the point of sampling. The hydrostatic pressure may cause the rate of filling to vary with depth, so that it is not proportional to the stream velocity. This effect can be eliminated by using a sampler unaffected by hydrostatic pressure, a condition which is approximated by the collapsible container type with intake facing into the stream. The rate of filling can also be controlled mechanically by regulating the air release or by adjusting the size of intake. Still another means of correcting for this effect of hydrostatic pressure on the rate of filling is to vary the rate at which the sampler is moved vertically, but this method presents operating difficulties that make it impractical. When the depth-integration method is properly used it will give accurate results for both mean concentration and particle size, providing the time of filling is sufficient to compensate for instantaneous fluctuations at each point. Since this method requires only one sample in each vertical, the laboratory analysis is reduced to a minimum.

At present there is no equipment available in this country which is designed to give the proper rate of filling under all conditions of operation. A collapsible bag type of sampler, which is claimed to satisfy the requirements, is being used in Russia.

In depth-integration sampling, a slow filling type of sampler must be used. In using this method it has frequently been the practice to lower a closed sampler to the bottom, then open it, and raise it at such a rate that the sampler would reach the surface before the container was entirely filled, thus assuring that water from every point in the vertical was taken in. When a sampler with a fixed-volume container is operated in this manner a portion of its capacity is filled in a moment after the valve is opened. This initial filling, which is induced by the difference in pressure outside and inside the container and, therefore, proportional to the depth of submergence, is described fully in Section 42. It is evident that during this period the filling rate is not a function of the velocity and, hence, the sample as a whole is not representative of the average water-sediment mixtures in the vertical. To avoid this difficulty the sampler should be open during the descent as well as the ascent and should be lowered and raised at a uniform rate such that the round trip is made before the container is entirely filled. This procedure does not assure a perfectly integrated sample, but, for practical purposes, it is probably satisfactory, if the stream is not too deep to permit the round trip to be made before the container is filled.

The accuracy of this method will be diminished if the sampler used does not permit sampling close enough to the stream bottom. However, particular care must be exercised to prevent disturbing the bed material in such a way that it is washed up into the sampler.

22. Comparative summary of methods--Table 6 presents a comparative summary of the various methods in use for observing sediment in a vertical. The attempt has been made to make this table complete so that a ready comparison between existing methods is possible. The number of samples, the duration of a sampling interval at a single point, and the manner of conducting the depth-integration method so as to compensate for instantaneous fluctuations in sediment concentration are not shown in the table.

TABLE 6

METHODS OF SELECTING SAMPLING POINTS IN A VERTICAL

Method and description	Discussion	Reliability and accuracy for determining: Concentration only*	Reliability and accuracy for determining: Concentration and particle size	Practical considerations	Number of samples and analyses per vertical
Single-point A single sample secured at the surface.	Arbitrary method unless coefficients have been determined from previous, more complete sampling, then it is somewhat empirical.	Not reliable or necessarily accurate even when a coefficient has been determined.	Not at all reliable or accurate.	Simplest of all present methods, rapid and easy to use. Readily adapted for use by unskilled observers. Requires previous more exact sampling for justification.	One sample and one laboratory analysis.
Single-point A single sample secured at any point in the vertical other than the surface.	Arbitrary method unless coefficients have been determined from previous, more complete sampling; then it is somewhat empirical. A common point to sample has been 0.6 depth.	Generally not reliable or accurate even when a coefficient has been determined, but more so than a single surface sample. Thoroughness of preliminary investigations will determine, somewhat, the reliability and accuracy.	Not reliable or accurate.	Simple, rapid, and easy to use, but fractional depth measurements makes it less adaptable to use by unskilled observers than single surface method. Requires previous, more exact sampling for justification.	One sample and one laboratory analysis.
Two-point Two points selected arbitrarily for convenience and adaptability to the skill of the observer.	Arbitrary method with no rational justification.	Generally not reliable or accurate for all conditions of a given stream.	Generally not reliable or accurate.	Fairly simple, rapid, and easy to use. Can be used by dependable observers even though inexperienced.	Two samples may be combined if of equal volume for a single analysis.
Three-point Arbitrary selection of points at surface, mid-depth, and bottom with equal weights.	Points located arbitrarily.	Not necessarily reliable or accurate for all stream conditions.	Not necessarily reliable or accurate.	Sampling at surface, mid-depth, and bottom is the most simple and easiest to use of all methods requiring more than two samples. Can be used by dependable observers even though inexperienced.	Three samples may be combined if of equal volume for a single analysis.
Three-point Arbitrary selection of points at surface, mid-depth, and bottom with weights of 1, 2, and 1 applied, respectively.	Basis of method is assumption that the averages of surface and mid-depth samples represents upper half of discharge and average of mid-depth and bottom represents lower half.	Not necessarily reliable or accurate for all stream conditions.	Not necessarily reliable or accurate, but more so than three points, surface, mid-depth, and bottom with equal weights.	Sampling at surface, mid-depth, and bottom is the most simple and easiest to use of all methods requiring more than two samples. Can be used by dependable observers even though inexperienced.	Three samples. If of equal volume, surface and bottom samples may be combined for single analysis.
Precise A relatively large number of point samples at known locations in each vertical simultaneous with velocity measurement.	Rational method for use primarily in special investigations. Number of sampling points depends upon depth of stream, the velocity and sediment distribution, and the degree of accuracy desired.	Reliable and accurate. Accuracy depends upon the curvature of the velocity and sediment distribution curves and number of samples. The most accurate method in use at present.	Reliable and accurate. Accuracy depends upon curvature of particle distribution curve, curvature of velocity and sediment distribution curves, and number of samples. The most accurate method in use at present.	Not adapted to routine sampling because of the excessive work required. Its use is limited to research or preliminary investigations. Laboratory work excessive as all samples must be analyzed separately.	Minimum of four or five samples all to be analyzed separately.

Straub Sampling at 0.2 and 0.8 depth, applying coefficient obtained by mathematical derivation for both linear and curvilinear sediment distribution. For linear distribution values weighted 5/8 and 3/8 for 0.2 and 0.8 depth, respectively.	Rational method, best adapted for use where the vertical sediment distribution curve approximates a straight line, and the velocity distribution is fairly constant.	Accuracy and reliability depends almost entirely upon the agreement of the actual to the assumed sediment and velocity distribution. In most cases quite reliable.	Theoretically not sound if sediment distribution is curvilinear, but, practically, one of the most reliable methods.	Field work relatively simple for skilled observer but adaptable also to dependable observers, even though inexperienced.	Two samples and two analyses.
Luby Sampling points selected at the middle of increments of depth representing equal portions of stream discharge.	Rational method if a sufficient number of samples are collected. The samples, if of equal volume, can be combined and composite representative of the mean concentration and composition in the vertical. Number of points, with respect to depth depends primarily upon curvature of sediment distribution curve; to a lesser extent, generally, upon curvature of vertical velocity curve.	Reliable and accurate if a sufficient number of samples are collected. One of the most reliable and accurate of the present methods except the precise.	Fairly reliable and accurate if a sufficient number of samples are collected. One of the most reliable and accurate of the present methods except the precise. Enough samples should be taken so that one will be close to the stream bed.	Requires either an assumed velocity distribution or previous velocity measurements. Too complicated for use except by trained hydrographers. Because of sampling more points a better representation of the actual sediment distribution will probably be obtained than with the Straub method.	Minimum of five samples. May be combined if of equal volume for a single analysis.
Depth-integration Single sample collected from all points in the vertical usually obtained by lowering and raising a slow-filling sampler at constant rate. These usually consist of ordinary milk bottle types or specially designed slow-filling samplers.	Rational method only if sample is collected proportional to velocity.	Relatively reliable under usual conditions but its accuracy varies as most of the present equipment does not sample proportional to the velocity, and many samplers do not approach close enough to the bottom. As used, accuracy depends upon depth of stream and type of sampler.	Relatively reliable under usual conditions but its accuracy varies as most of the present equipment does not sample proportional to the velocity, and many samplers do not approach close enough to the bottom. As used, accuracy depends upon depth of stream and type of sampler.	As commonly used with simple slow-filling samplers this method is simple, rapid, easy to use, and well adapted to dependable observers, even though inexperienced. No previous measurements necessary.	One sample and one analysis.

*For methods where coefficients are used comments apply only to individual observations or short period investigations as over long periods totals may have a fair degree of accuracy.

These factors will necessarily have varying importance with different types of investigations and the size and characteristics of the stream.

As a practical matter, in certain investigations where economy is essential, it may be necessary to have routine samples taken by unskilled resident observers, which will necessitate the use of the more simple methods. The table shows the adaptability of the methods under these conditions.

In considering Table 6 it should be noted that, although the depth-integration method requires only one sample for concentration determinations, this advantage may be partially offset by the probable increased accuracy of the Straub or Luby methods, wherein more samples tend to offset error due to very rapid fluctuations in the sediment concentration. If size analysis of the sediment is desired it may be necessary, for ordinary concentrations, to obtain as many samples by the depth-integration method as by the Luby method in order to have sufficient sediment for the analysis.

V. FREQUENCY OF SAMPLING

23. Factors which affect the sampling frequency--Investigations of suspended sediment in streams are usually concerned primarily with the development of long-term continuous records of sediment discharge and, to a lesser extent, with shorter, more intensive, research investigations. The main purpose of the former, and in some cases in the latter, is to obtain a hydrograph of sediment discharge sufficiently accurate for the particular problem in hand. In many present day investigations, knowledge of the total sediment concentration is required, and there is also a growing demand for particle size data as well. This is an additional factor to be considered in deciding how often to take samples. In addition to being one of the critical considerations in sampling procedure, the frequency of sampling is probably the most difficult to determine on a rational or analytical basis because of the great number of factors tending to produce considerable variation in sediment concentration.

In determining the frequency of sampling, the purpose of the investigation, the cost of various procedures, and the fluctuation of sediment concentration must all be considered. Generally, the latter is the most important but the problem is complicated by its wide range of variation. Numerous attempts have been made to correlate suspended sediment discharge with water discharge but they have not been successful except in certain isolated cases on large rivers. The following sections present briefly the variations that can occur in sediment concentration, the factors causing them, and the manner of minimizing their effects in present observations.

In the following discussion some of the difficulties of securing accurate data on sediment discharge will be pointed out, and the comparatively large errors which often are found in estimates of sediment discharge will be indicated. Those who work in field involving factors having a comparatively small range may consider these errors discouragingly large, and the basic data of doubtful value. In the field of sediment transportation, however, the range of values of sediment discharge is very great. For example, the Rio Grande River at San Marcial, New Mexico, carries an average sediment load of 1.42 per cent, while the North Fork of the Couer d'Alene at Erraville, Idaho, carries only about 0.0074 per cent and the Gasconade at Rich Fountain, Missouri, about 0.0076 per cent. The ratio of the average content of the Rio Grande to that of the other two rivers is about 200 to 1, and these examples probably do not represent the extremes in either direction.

Engineers are frequently faced with the necessity of estimating the rate at which a reservoir will fill up, or some other problem which involves the average magnitude of the sediment load of a stream. The expenditures affected by this determination are often very large, sometimes being in the order of a million dollars. Accurate data is therefore very essential, but, usually, the available information is very meager. Because the range of average concentrations which might reasonably be used is so wide, the engineer, if he has no data at all, may easily make an error of several hundred per cent in estimating sediment loads. Even with relatively unsatisfactory records the engineer's estimate for a given case will very probably be materially less in error than if he has no records at all for that stream. While every effort should be made to get records of a high degree of accuracy, the opportunity of increasing the accuracy of the engineer's estimates of sediment load should not be neglected simply because it is not practicable to secure results which have the degree of accuracy which is customary in other fields.

24. <u>Variations in sediment concentration and factors producing them</u>--Variations in suspended sediment concentration are of two distinct types; namely, rapid, nearly instantaneous fluctuations related to stream turbulence, and variations occurring over a longer period of time, ranging from a few minutes to several weeks or more. The latter type is not a function of turbulence but can be attributed rather to watershed, rainfall, and stream characteristics.

Fluctuations due to turbulence can be compensated for either by securing a series of samples at one point or by increasing the time of collecting a single sample sufficiently to secure a satisfactory average. The importance of momentary fluctuations has been generally recognized and attempts have been made to minimize their effect, as is evidenced by the recent development of a large number of slow filling samplers.

A sampling program must be governed by variations that occur over longer periods of time than those that can be attributed to turbulence. Variations of long duration are more difficult to take into account and do not allow a fixed sampling frequency, except probably in very special investigations, because of the complex relationship of a great number of variable factors.

Briefly, the most important factors influencing sediment concentration fluctuations of the latter type are:

<u>a</u>. storm characteristics, such as frequency, intensity distribution, amount and kind of precipitation;

<u>b</u>. features of the drainage area, such as size, shape,

topography, culture, geographical location, and type and condition of soil and vegetation; and

c. stream characteristics.

The magnitude of run-off and its suspended load are determined by an interrelation of these factors, and changes are usually manifested by changes in the stage of the stream.

The size of the drainage area of a stream has considerable effect on its sediment concentration. For small rivers the sediment and water discharge may be dependent on only one intense local storm and on local watershed characteristics. For larger rivers, where the run-off may result from several storms occurring in several different types of watersheds, the probability of extreme conditions of run-off is greatly lessened. One would expect, therefore, the relative importance of some individual factors to be, in general, inversely proportional to the size of the drainage area above the sampling station.

Obviously, a change in stage is the most convenient criterion for the frequency of sampling because it is usually the first direct indication of surface run-off from the watershed. A change in stage is generally accompanied by a change in sediment concentration. It is important to note, however, that the variations in concentration before a peak stage due to storm run-off are generally different from those occurring after the peak. Concentrations often change very rapidly and erratically preceding a peak. After the peak the concentration usually changes more gradually and at a fairly consistent, though not necessarily a uniform, rate. The sampling frequencies, to be used particularly on smaller streams, should be determined with these considerations in view. However, it is possible that storms, relatively small in scope in comparison to the size of the drainage area, occurring on areas where severe erosion could occur, would change the sediment concentration and yet produce no appreciable change in stage. These variations, and some others, should be studied in routine investigations by sampling at stated periodic intervals even when no changes in stage occur.

25. <u>Errors in sediment discharge determinations due to infrequent sampling</u>--The changes in sediment concentration accompanying rapid changes in stage, especially in small streams, may be of such magnitude that unless frequent samples are taken, large errors may be introduced in the determination of total yearly sediment discharge. For example, it was found in Coon Creek at Coon Valley, Wisconsin (34) with a drainage area of 77 sq.mi., that 90 per cent of the total sediment discharge in 15 months occurred within a period of 10 days, or 2.2 per cent of the time. In West Tarkio Creek, near Westboro, Missouri, with a drainage area of 127 sq.mi., 90 per cent of the total sediment discharge in a 15-month period occurred in 2.2 per cent of the time. Table 7 illustrates that these examples are not unusual for small streams. Data from a number of gaging stations (34) are tabulated, giving total suspended load for a period of 15 months and the maximum daily load during that period. The maximum load in 1 day (0.2 per cent of the total time) is shown to be, in most cases, more than 10 per cent of the total load for the period. Hence, the necessity of obtaining accurate samples from the smaller streams frequently during such times is apparent.

Detailed data from a major rise on Coon Creek (10) was analyzed to illustrate how errors are introduced into daily and yearly sediment discharge determination in using various intervals of sampling and by

TABLE 7

SUSPENDED SEDIMENT DISCHARGE CHARACTERISTICS OF SMALL STREAMS (34)

Stream and Location	Drainage Area	Suspended Sediment Discharge Total for 15 months	Maximum Daily	Maximum Daily
	sq.mi.	tons	tons	per cent of total
E. Limestone Cr. near Ionia, Kan.	23.7	179,400	41,700	23.2
Elm Cr. near Ionia, Kan.	23.2	154,000	44,200	28.7
E. Limestone Cr. at Ionia, Kan.	51.6	297,500	83,200	28.0
W. Buffalo Cr. near Jewell, Kan.	15.3	118,200	28,000	23.7
W. Buffalo Cr. at Jewell, Kan.	16.3	87,500	20,600	23.6
E. Tarkio Cr. at Blanchard, Ia.	200.0	248,100	42,000	16.9
W. Tarkio Cr. near Westboro, Mo.	127.0	245,100	54,500	22.2
East Fork of Big Cr. near Bethany, Mo.	95.0	379,500	29,800	7.9
West Fort of Deep R. near High Point, N. C.	33.0	43,100	7,910	18.3
East Fork of Deep R. near High Point, N. C.	13.9	21,200	2,600	12.2
Deep R. near Randleman, N. C.	124.0	76,200	4,990	6.5
Muddy Cr. near Archdale, N. C.	14.2	7,540	564	7.5
Uharie R. near Trinity, N. C.	11.3	18,700	2,680	14.3
Horsepen Cr. at Battleground, N. C.	15.9	11,000	965	8.8
Stillwater Cr. at Stillwater, Okla.	165.0	118,400	61,800	52.2
West Fork of Brush Cr. near Stillwater, Okla.	13.1	15,300	5,610	36.7
Council Cr. near Stillwater, Okla.	30.2	68,800	10,400	15.1
N. Tiger R. near Moore, S. C.	162.0	87,500	3,860	4.4
S. Tiger R. near Reidville, S. C.	106.0	44,300	3,710	8.4
S. Tiger R. near Woodruff, S. C.	174.0	121,500	6,650	5.5
Tiger R. near Woodruff, S. C.	351.0	349,100	13,800	4.0
Deer Cr. at Chilton, Texas	81.8	493,000	127,000	25.8
Big Elm Cr. near Temple, Texas	68.5	613,000	102,000	16.6
Big Elm Cr. near Buckhotts, Texas	166.0	655,800	99,100	14.3
N. Elm Cr. near Ben Arnold, Texas	30.3	78,400	22,800	29.1
South Fork of Palouse R. above Paradise Cr. near Pullman, Wash.	81.1	19,600	2,210	11.3
South Fork of Palouse R. at Pullman, Wash.	132.0	33,200	3,580	10.8
Paradise Cr. near Pullman, Wash.	37.0	7,630	789	10.3
Dry Fork of South Fork of Palouse R. at Pullman, Wash.	7.4	1,980	430	21.7
Missouri Flat Cr. at Pullman, Wash.	27.5	10,000	1,500	15.0
Four Mile Cr. at Shawnee, Wash.	73.1	29,000	4,600	15.8
Little LaCrosse R. near Leon, Wis.	77.1	91,900	13,500	14.7
Coon Cr. at Coon Valley, Wis.	77.6	97,200	35,000	36.1
Coon Cr. near Stoddard, Wis.	119.0	105,200	17,600	16.7

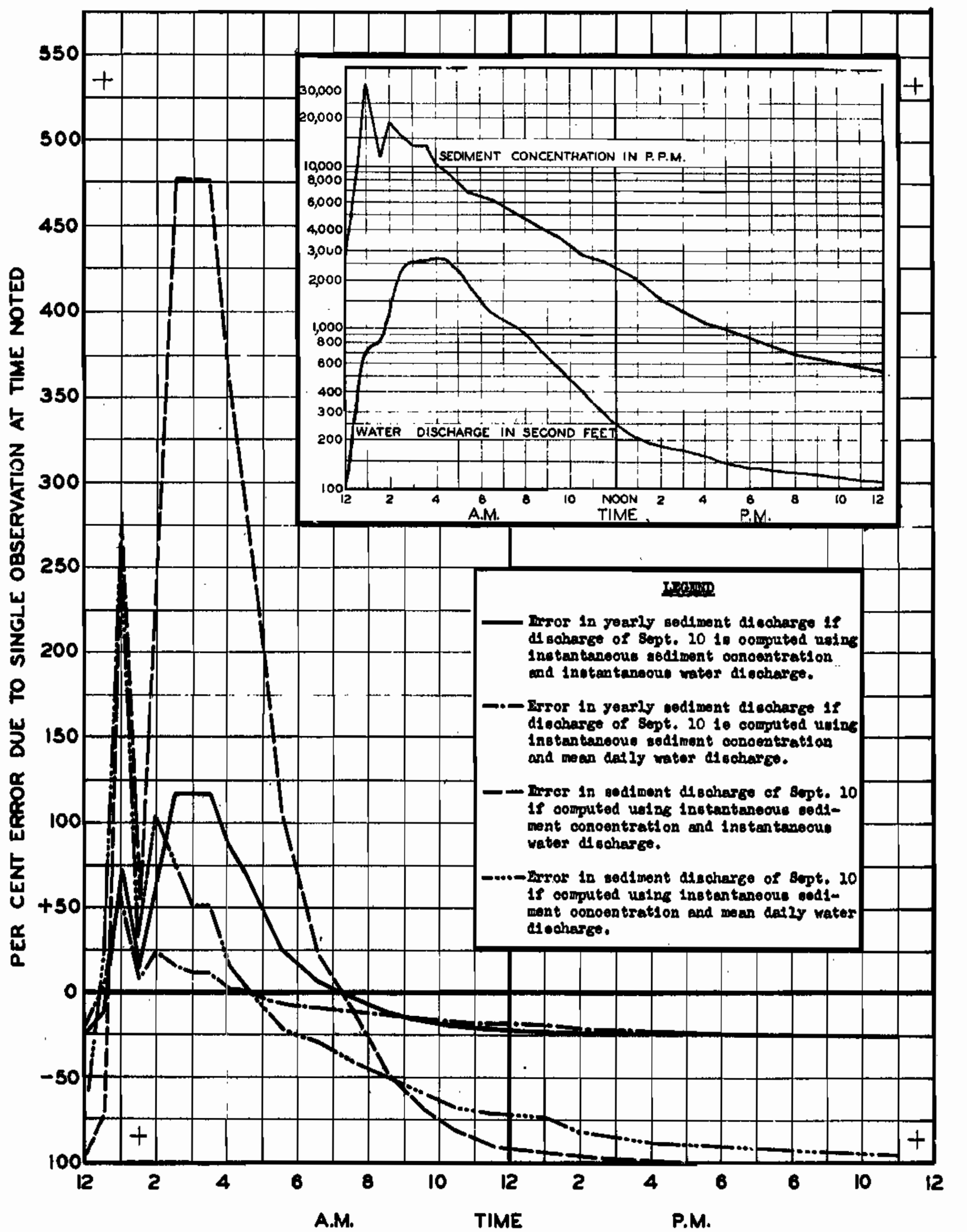
beginning at different times during the rise. Fig. 6 illustrates how errors are introduced in daily and yearly sediment discharge determinations when the sediment discharge for the day was based on only one observation. The daily sediment discharge was computed in two ways:

a. by using the instantaneous sediment concentration and mean water discharge for the day, and

b. by using the instantaneous sediment concentration and the water discharge at the time of sampling.

The maximum error introduced in the computed yearly sediment discharge by computation a would have been 60 per cent, which would have occurred if the measurement had been made at 1:00 A.M. By computation b a measurement at 3:00 A.M. would have produced a maximum error of 116 per cent. These are the extreme errors for the data analyzed but appreciable errors in yearly sediment discharge determinations would also have occurred if single daily samples taken at other times during the rise had been used. It is probable that in most cases computation b would be avoided by using either a value of mean daily discharge obtained from a water stage recorder, or from a hydrograph constructed from gage readings, or by using the unit-hydrograph method. However, it may be difficult to construct a hydrograph if only a single daily gage reading is taken, as is the case in obtaining a number of present water discharge records. Thus, Fig. 6 shows the need of obtaining accurate records not only of the sediment concentration, but of the water discharge as well.

The importance of starting to sample during the early part of the high run-off period in small streams and the effects of using different sampling intervals are shown in Fig. 7. This figure shows the error introduced in the sediment discharge determination for a given day, with

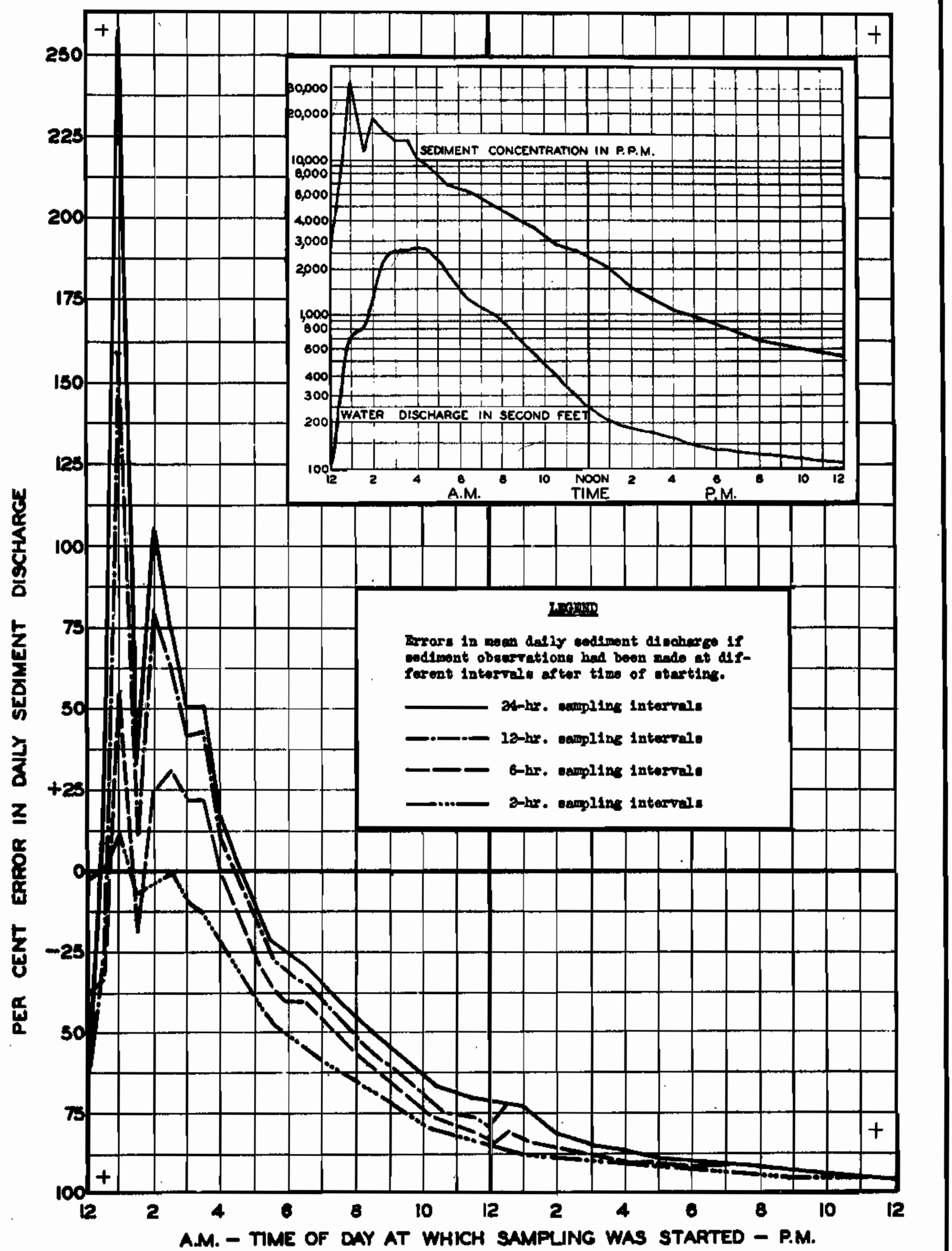


ERRORS IN SEDIMENT DISCHARGE

DUE TO SINGLE DAILY SAMPLE

COON CREEK AT COON VALLEY, WIS.

SEPT. 10, 1938



ERRORS IN DAILY SEDIMENT DISCHARGE
DUE TO DIFFERENT SAMPLING INTERVALS
COON CREEK AT COON VALLEY, WIS.
SEPT. 10, 1938

varying elapse of time from the beginning of the rise to the start of sampling and with varying sampling intervals. For example, if the observer had begun at 6:00 A.M. and sampled at 2-hr. intervals throughout the remainder of the day, the error in the sediment discharge determination for the day, due primarily to missing the early part of the high flow, would have been 51 per cent. The sediment discharge indicated by the graphs in Figs. 6 and 7, was computed by multiplying the mean water discharge for the day by the mean sediment concentration, weighted by the ratio of sediment to water discharge at the time of sampling. Errors in determination of the total annual sediment discharge resulting from the errors of one day would be approximately one-fourth of those shown in Fig. 7. As illustrated in this figure, the accuracy is greatly increased by frequent sampling, providing sampling is started soon after the stream begins to rise. However, the curves also show that frequent sampling is comparatively unimportant if the early part of the rise has been missed; that is, the error introduced by missing the early part of the hydrograph cannot be compensated for by more frequent sampling on the falling stage.

In Table 8 are shown the errors introduced in using various sampling intervals during rising and falling stages in the hydrograph of Fig. 6. The table illustrates that sampling during the falling stage need not be as frequent as on the rising stage. For example, more accurate results could have been obtained in this instance if 1/2-hr. intervals had been used on the rise and 4-hr. intervals on the fall than if 1-hr. intervals had been used throughout. Furthermore, only 13 observations would have been required in the former method as compared with 24 observations in the latter.

TABLE 8

ERRORS IN DETERMINATION OF DAILY SEDIMENT DISCHARGE
WITH VARIOUS SAMPLING INTERVALS

Coon Creek at Coon Valley, Wisconsin -- September 10, 1938

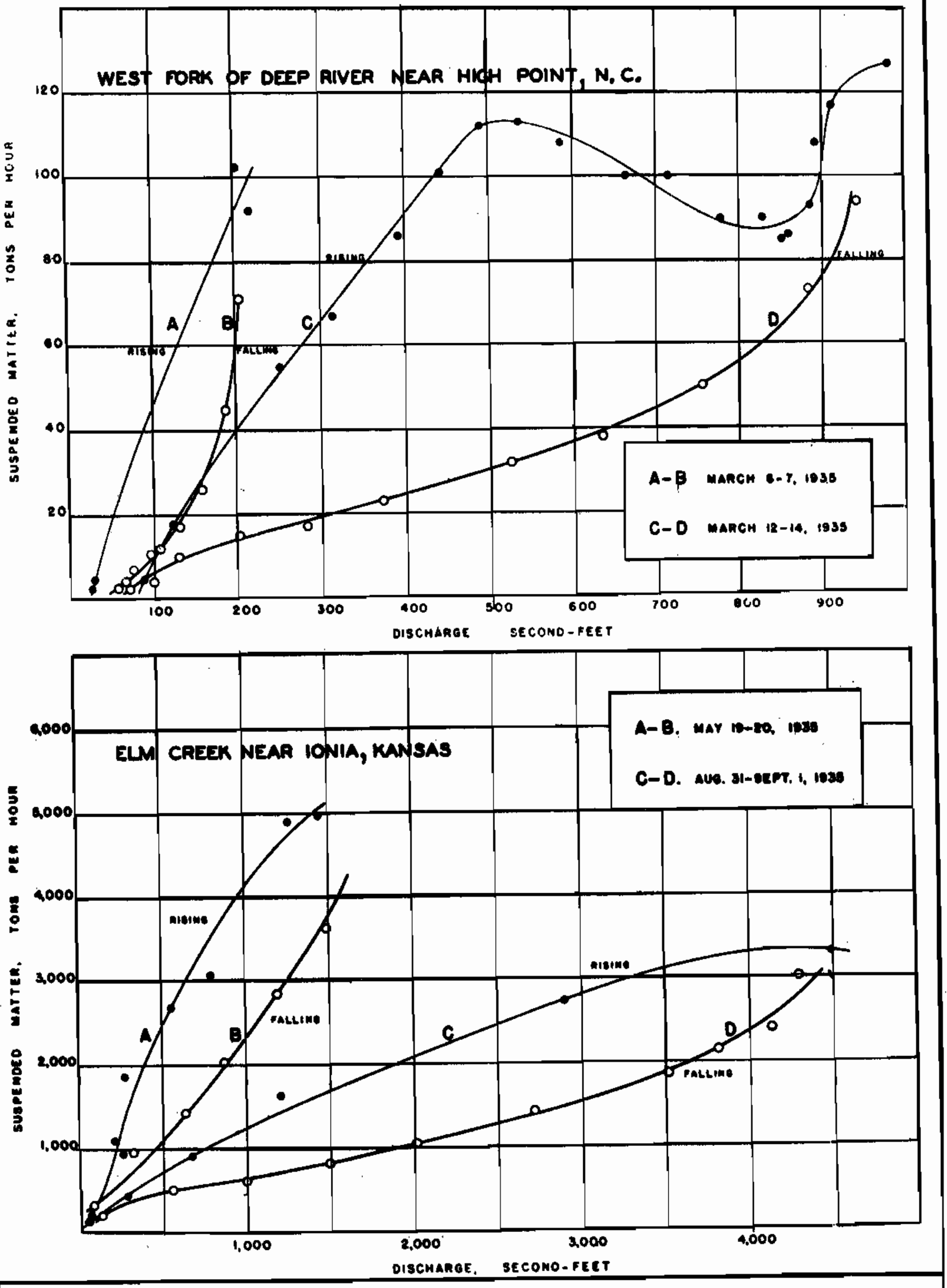
Sampling Interval (hours)		Per cent Error	Total Number of Observations During Day
Rising stage	Falling stage		
0.5	0.5	0.5	48
0.5	4.0	1.4	13
0.5	6.0	3.5	11
0.5	8.0	5.3	10
1.0	1.0	4.4	24
2.0	2.0	6.4	12
4.0	4.0	13.4	6
6.0	6.0	27.0	4

The data analyzed are taken from only one small stream and are not representative of all streams. However, since Table 7 showed Coon Creek to be not unusual for the maximum percentage of annual sediment discharge occurring in one day, it seems likely that the order of magnitude of the errors discussed are not uncommon for similar small streams. The errors illustrated would probably decrease as the size of the stream increases.

26. Other factors affecting the frequency of sampling--If a sufficient number of well spaced samples are taken, a reasonably accurate sediment concentration hydrograph can be prepared. When the sediment discharge is computed on the basis of such a graph the errors due to infrequent sampling will depend largely upon personal judgment in supplying data between observed values. It is probable that the missing data can be supplied from a sediment concentration hydrograph with better results than by using the mean concentration indicated by several samples weighted according to water discharges at the times they were taken.

Some attempts have been made to correlate water and sediment discharge in order to compute sediment discharge during the intervals between sediment observations. These attempts, which have generally met with little success, are justifiable only when an estimate must be made and no better means are available. For large rivers the method has been found to be fairly successful for determining total quantities over long periods. In sediment investigations on the Missouri River, Dr. L. G. Straub (50) obtained a relationship which held quite well, up to a certain discharge above which it was not reliable. Dr. Straub considered this method satisfactory at stations where it was economically impractical to obtain frequent routine samples. The U. S. Waterways Experiment Station, Vicksburg, Mississippi, concluded (54) that "the quantity of coarse materials (0.0375 mm. or larger) transported, probably bears a definite relation to river stage, but the quantity of fine material transported is a function of the silt content of influent waters." In the Colorado River it was found that, although there was no apparent relation between the quantity of fine silt and the discharge, there was a definite relation between the load of coarser particles and the discharge.

Certain individual factors, characteristic of the watershed, increase in importance as the size of the drainage area decreases, and, therefore, it is reasonable to expect that for small watersheds a water-sediment discharge relationship would probably be less reliable than for large watersheds. Numerous data substantiate this point. Two illustrations from small streams are presented in Fig. 8, showing the large difference between the sediment discharge on a rising and on a falling stage, and during two run-off periods. The suspended sediment concentration is seen



RELATION BETWEEN
WATER DISCHARGE AND SEDIMENT DISCHARGE
FOR TWO SMALL STREAMS

to vary several hundred per cent at the same water discharge. These, and other available data, indicate that the suspended sediment hydrograph may be somewhat similar to the shape of the water discharge hydrograph, but they are generally not synchronized with respect to time. The peak sediment discharge can occur either before or after the peak water discharge. One explanation advanced (33) is that sediment will travel downstream with the actual stream velocity while the peak water discharge will proceed with the flood wave velocity. Flood wave studies have shown that stream velocity and flood wave velocity are usually not of the same magnitude; also that one is not in all cases larger than the other. Because these factors complicate the correlation of sediment and water discharges, it seems impossible to make a satisfactory determination of sediment discharge at any given time from the known water discharge.

From the foregoing discussion it appears that the best method to obtain reliable records of sediment discharge is to sample frequently enough to determine the sediment concentration hydrograph during the period in question. In general, this will probably necessitate more frequent sampling on rising than on falling stages. Since reasonably satisfactory rules specifying the frequency of sampling are difficult to draw up, the final decision in most cases in the past has been made by the field engineer or observer.

27. <u>Present practice</u>--A definite schedule of sampling has been set up by the Tennessee Valley Authority for each of its stations. The schedules are based upon considerations of past records of sediment and water discharge at the stations, the drainage area characteristics, and

the number and location of the other stations to be handled by a single field party. For example, at one station with a drainage area of about 500 sq.mi., routine samples are taken each week. During flood flows and on each rise of the river, samples are collected at 4-hr. intervals while the stage is increasing and at 12-hr. intervals after the crest. For main river stations with large drainage areas the corresponding intervals are 12 and 24 hrs. The field man attempts to arrange his visits to each station so that one set of samples is obtained at or just before the crest stage. He also collects additional samples whenever the sediment concentration changes noticeably, even though the stage may remain unchanged.

In the Ft. Peck U. S. Engineer District, a measurement is made each day during the spring high water and each week throughout the remainder of the year except during the winter months when observations are discontinued. The Vicksburg U. S. Engineer District collects samples once each week from the lower Mississippi and its larger tributaries, except during periods of rapidly changing stages, when more frequent observations are made.

In the extensive investigations conducted by the Soil Conservation Service routine samples are generally taken each day. When stages are changing samples are taken more frequently, sometimes as often as every 30 min. In some cases electric alarm systems are being used to notify the observer when large rises in stage occur during the night, which would otherwise be missed.

Various sampling frequencies are used by the U. S. Geological Survey in a cooperative project with the Central States Forest Experiment

Station, conducted in the St. Francis River watershed in southeastern Missouri. At one station, with approximately 1300 sq.mi. of drainage area, samples are taken twice each day during medium and high stages and once each day during low stages. At another station, with a drainage area of 956 sq.mi., 1-hr. intervals are used during rising stages and 2-hr. intervals during falling stages. Samples are collected each day during low stages. At all other stations in the watershed 1-hr. intervals are used on the rise and 2-hr. intervals on the fall. Routine samples are collected twice each week during low stages.

A method suitable for large streams has been developed by the Iowa Institute of Hydraulic Research wherein each sediment observation is intended to represent an equal portion of the yearly discharge. In this method, the mean annual cumulative water discharge, as determined from previous records, is divided by the number of observations that are considered economically feasible, giving a value of water discharge which each sediment observation is intended to represent. Sampling intervals may then be determined by transferring daily gage readings into water discharge and adding the water discharges for consecutive days until a total is reached which corresponds to the value to be represented by each sample. At this time a sediment observation is made.

In a number of current sediment investigations samples are taken at regular intervals throughout the year, varying from twice each day to once each week. Some of these investigations are on large streams where the sediment concentration does not vary a great deal in short intervals of time and, hence, the problem of determining sediment discharge is not as difficult as on smaller streams.

VI. DEVELOPMENT OF SUSPENDED SEDIMENT SAMPLERS

28. General history of sampler development--The suspended sediment sampler, used in the first silt investigation in European rivers, in the beginning of the 19th Century, consisted of a can or container with which to dip samples from the water surface. An ordinary water pail was used by the earliest investigators in the Mississippi River about 1840; apparently no attempt was made at that time to obtain samples from below the water surface.

The first sampler to be developed beyond the stage of a simple pail or can was probably the keg sampler used by Professor Forshey in the Mississippi River at Carrollton, Louisiana, in 1851. This sampler, as described by Humphreys and Abbott (26), was a small, weighted keg, equipped with a flap valve in each end. As it was lowered, the keg was maintained in a vertical position and the flap valves opened upward due to the reaction of the water, and closed when the sampler was halted at the desired sampling depth.

Investigating silt conditions in the Mississippi River at Helena, Arkansas, in 1879, Mr. J. B. Johnson found that the openings in the top and bottom of the keg sampler did not permit free passage of water sediment as the sampler was lowered, with the result that at the time of sampling, the keg contained a mixture from all depths. Mr. Johnson developed the sampler shown in Fig. 9, which was designed to overcome this objection. This sampler consisted of a vertical, cylindrical container with a flap valve at each end which would close when the sampler touched the river bed (42). In principle it was similar to the keg sampler, but the container had a uniform cross section and both end areas were completely uncovered while the sampler was being lowered to the sampling point.

The "slip bottle" used in the Missouri and Mississippi Rivers in 1880-81 was the first of the instantaneous trap samplers. This sampler, and its improved design, the "double slip bottle", shown in Fig. 15, functioning as described in Section 54, obtains an instantaneous sample from a relatively undisturbed stream flow. The effect of the sampler on stream flow and the accuracy of the instantaneous action were probably not considered in designing the sampler.

The horizontal trap, shown in Fig. 21, an instantaneous type sampler used extensively in recent years, dates back to the Leitz horizontal sampler described by Mr. C. T. Johnston in Engineering News of 1902. It was used by Dr. Elwood Mead of the U. S. Department of Agriculture for investigations in rivers of western United States and is probably the first sampler designed with the view to trapping a sample with a minimum disturbance to the flow.

As previously stated, the ordinary open container, such as a pail, can, or bottle, predates the other means of water-sediment sampling. The first improvement in this simplest type of sampler was the use of an ordinary stopper in a small-mouth bottle with provision for its removal at the desired depth of sampling. Fig. 41 shows the simple bottle type sampler as described in Engineering News of 1893.

It is not known definitely when a common water pump was first used to obtain sub-surface samples from a stream, but it was probably used in 1843 in investigations by Professor Riddell. Water samples were pumped up from the different depths with a common water lift pump also in investigations conducted by R. G. Kennedy (30) in the Sirhind Canal, India, in 1893 and 1894.

From the foregoing discussion it is apparent that the development of water-sediment samplers has not progressed along any definite trend and the basic types that are used today are much the same as those used in the first investigations.

29. <u>Recent developments of samplers</u>--Developments of samplers for recent investigations have consisted primarily of improvements upon the original basic types. Weight has been added either as an integral or a separate part of the sampler. Emphasis has been placed upon streamlining to reduce the current drag and to increase the accuracy of determining the depth of sampling, thus adapting samplers for use in deeper, swifter streams.

The time-integrating sampler, a distinctly new class, has evolved from the realization that the suspended sediment concentration is subject to rapid fluctuations and that the average concentration at a point will not be accurately represented by a single instantaneous sample. In samplers of this class, the basic principle is to secure over a considerable period of time a sample representative of the average sediment condition. Many of the so-called time-integrating samplers are only modifications of the ordinary slow filling, bottle type sampler with various devices provided for opening and closing the sampler at the desired sampling point. Recently, however, a number of samplers have been developed with smooth, slow filling, which are being used extensively and with considerable success.

The photo-electric cell, as a means of securing a measure of sediment concentration by its relation to turbidity, has been subject to considerable experimentation. The conclusion of previous investigation was that this method is not practical for general field use because of the unreliability of correlations between turbidity and sediment concentrations due to such effects as size, color, and light reflecting properties of sediment particles.

VII. REQUIREMENTS OF SAMPLERS

30. Previous concepts of sampler requirements--About 1875 it was realized that ordinary pails or other crude equipment were not adequate as suspended sediment samplers and certain basic requirements were developed. One of the earliest investigators, Mr. J. B. Johnson (42), who designed the trap sampler shown in Fig. 9, considered the following requirements as fundamental in a satisfactory sampler:

> a. it should have capacity for a fair specimen of the water which immediately surrounds it,
>
> b. while it remains at a point the water-sediment mixture received from the stream should be unchanged, and
>
> c. it should bring its contents to the surface intact.

It was not until about 1928 that additional statements of sampler requirements appeared, prompted probably by an increased interest and activity in suspended sediment studies. Criteria for design of samplers have been prepared by the Rock Island U. S. Engineer Office, by Mr. H. W. Mundt (37), of the Missouri State Geological Survey, and by Dr. L. G. Straub (50), formerly of the Missouri Division Office of the U. S. Engineer Department. These criteria show a definite development in the knowledge and appreciation of the factors involved in securing representative sediment sampler. The outstanding points from these lists of requirements are:

> a. the sampler should be simple in design, durable, and all parts should be standard to permit replacement and interchange,
>
> b. the samples should show the same sediment concentration as existed at the point and time of sampling,
>
> c. provision should be made for opening and closing at the desired sampling point,

d. a number of seconds should be required for filling,

e. the equipment should be portable and suitable for operation by one, or not more than two, observers, and

f. the sampler should have a volume control.

31. Requirements of an "ideal" sampler--The advantages of having only one sampler so designed that it will meet the requirements of all possible stream and sediment conditions are readily appreciated. The attainment of an "ideal" sampler seems impossible, but the following requirements of such a sampler are listed with a view to aiding in future design as well as in eliminating some of the present unsatisfactory types:

a. The sample collected must be representative of the water-sediment in the immediate vicinity of the sampling point or sampling zone at the time of sampling.

b. The suspended sediment must not be separated from the water at the point of entry into the sampler due to any sudden change of flow characteristics of the water; i.e., turbulence, velocity or direction of flow. Thus, there must be no appreciable disturbance by the sampler upon the flow which would increase or decrease the concentration of sediment in the sample collected.

c. The sample collected at a point must not be contaminated by water or sediment at other depths in the stream section. That is, the sampler would be arranged to open at the desired point and to close when filled, preferably by manual control.

d. The volume of the sample must be sufficient to satisfy the laboratory requirements for the size analysis of the sediment as well as the regular "parts per million" determination.

e. The sampler must be adaptable for use in streams of any depth and for sampling at any desired depth of the water from the surface to the bottom.

f. The sampler should be portable and adaptable for use by an operator wading in a shallow stream or working from a boat or bridge in a deep river.

g. The sampler should allow the entire sampling operation at a cross section to be made in a minimum of time.

h. The sampler should be streamlined and of sufficient weight to reduce to a minimum its deflection from the vertical due to drag when used in deep, swift streams.

i. Simplicity of design and construction are important from the standpoint of cost of the sampler and ease of maintenance and field repair.

j. It would be desirable to collect the sample in a container that can be shipped to the laboratory without transferring the sample to another container in the field. This would overcome the possibility of losing some of the sediment which might adhere to the sample container.

k. The sample should be collected in a transparent container so that the degree of settlement may be observed in the laboratory. However, in some streams it would be necessary to protect glass containers from being struck by heavy, suspended matter.

l. The sampler should be designed to take a sample instantly or over a longer period of time.

VIII. CLASSIFICATION OF SAMPLERS

32. General classification--For the immediate purpose of this study the suspended sediment samplers will be classified according to their mode of action. However, no rigid classification can be made because the characteristics of one type blend into those of another. There are objectionable and questionable features common to samplers of different classes and, to a varying degree, common to individual samplers of the same class. In the following sections the individual samplers are grouped so as to allow a class discussion of the various advantageous, as well as the questionable features. The outstanding characteristics of the general types of samplers are summarized in Table 9.

33. Vertical pipe samplers--A sampler with a vertical cylinder or pipe for the water sample container, not especially designed to obtain an instantaneous undisturbed sample, is classified for this study as a vertical pipe sampler. Illustrations of samplers of this class are shown by Figs. 9 to 12, and individual descriptions are given in Sections 47 to 51, respectively.

The chief advantage of the vertical pipe class of sampler is the simplicity of design. Although this class of sampler has been one of the principal types used in the past, they are not in common use in current investigations.

The mode of action for the various individual samplers of this class is essentially the same, regardless of such variations as length and diameter of sample cylinder and the operation of valves for trapping the sample. As the ordinary sampler of this class is lowered, or thrust

TABLE 9

CHARACTERISTICS OF SUSPENDED SEDIMENT SAMPLERS

General type sampler	Disturbance of flow characteristics	Intermixing of* sample with water above sampling point	Sampling action	Field handling of sample	Adaptability to various field conditions
Vertical pipe, Figs. 9 to 12	Excessive	Generally excessive*	Instantaneous	Necessary to transfer sample to another container.	Offer considerable resistance to current. Not satisfactory close stream bed.
Instantaneous vertical, Figs. 13 to 20	Questionable	None	Instantaneous	Necessary to transfer sample to another container.	Generally not satisfactorily streamlined or adapted for use near stream bed.
Instantaneous horizontal, Figs. 21 to 40	Tendencies minimized but effect not evaluated.	Slight possibility	Instantaneous	Necessary to transfer sample to another container.	Allows sampling very close to stream bed. Adaptable to any stream or depth.
Bottle, Figs. 41 to 58	Excessive but effect not evaluated.	Excessive if not opened and closed at sampling point.*	Bubbling or slow filling; after initial inrush.	Generally container with sample removable for shipment to laboratory.	Not capable of sampling close to bed of stream.
Time-integrating Figs. 59 to 68	Tendencies minimized but effect not evaluated.	To some extent if not opened and closed at sampling point.	Smooth filling after initial inrush.	Container with sample may be removable.	May be limited by depth of stream.
Pumping, Figs. 70 to 73	Tendencies minimized with proper control of intake tube and velocities.	None	Time-integrating.	Container with sample may be removed for shipment to laboratory.	Present designs not portable. Somewhat limited in use due to resistance to current. Where sediment is heavy, loss in pipe line may limit use.

* Assumes use of samplers to collect point samples.

through the water to the depth desired, the water flows up through the sampler from its lower end. When the downward motion is arrested at the desired depth, the valves automatically close of their own weight and the sample is trapped.

A somewhat different sampler of this class, shown in Fig. 12, is sometimes used in shallow streams. It consists of a pipe of sufficient length to reach from the surface to the bottom, and fills as it is lowered vertically into the stream. The pipe cuts a column of the water throughout the depth and encloses a sample of the entire vertical at the time of sampling. The sample thus obtained is actually a summation of instantaneous samples from each depth traversed by the mouth of the sample tube. An average sample throughout the depth of the stream, obtained in this manner, is not weighted according to the velocity distribution and, therefore, is not a true depth-integrated sample.

All except one of the objections discussed in Chapter IX are applicable to the vertical pipe class of sampler. The flow characteristics of the water entering the sampler are disturbed, especially when the individual sampler has valves at the ends of the sample cylinder in such a position as to prevent free flow through the cylinder. There is a definite possibility of intermixing of water from other than the desired sampling depth and particularly so in a few individual samplers equipped with valves inside of the sampling cylinders. The samples obtained, although not actually instantaneous, are not sufficiently integrated with respect to time to secure a mean value of the fluctuating sediment concentration. The samples collected by all vertical pipe samplers described in this report must be transferred to other containers for transporting to the laboratory.

34. <u>Instantaneous vertical samplers</u>--An instantaneous vertical sampler consists of a vertical cylinder which drops instantaneously and seats upon a flat plate, trapping a sample from the supposedly undisturbed stream flow. The sample cylinder, released by a messenger weight dropped down the suspension line, falls of its own weight or is forced downward by a coil spring. Illustrations of several typical samplers of this class are shown in Figs. 13 to 20. Other samplers using almost the same principle of operation as several shown in these illustrations, but more in the classification of the simple vertical container sampler, are shown in Figs. 14 and 17. Descriptions of the individual samplers of this class are given in Sections 52 to 57. An objective, and the principal advantage, of this type of sampler is to minimize disturbance of the stream flow before the sample is trapped.

Only two of the adverse features discussed in Chapter IX are characteristic of the vertical instantaneous samplers. These are:

<u>a</u>. The instantaneous action necessitates taking a series of samples to secure the mean of fluctuating sediment concentrations.

<u>b</u>. The non-removable sample container necessitates transferring the samples to other containers for shipment to the laboratory.

There is also the possibility that the direction of flow through the sampling zone will be altered or additional turbulence created by the sampler, and the sediment concentration affected thereby.

35. <u>Instantaneous horizontal trap</u>--The horizontal trap sampler is simple and widely used in present investigations. A sampler of this type consists of an open horizontal cylinder equipped with valves at the ends which can be closed instantaneously to trap a sample at any desired time

or depth. Water is allowed to pass through the horizontal pipe as the sampler is lowered to the sampling point. Samplers of this class, in the simple form, are illustrated by Figs. 21 to 30, and samplers of more elaborate design, streamlined and weighted, are shown in Figs. 31 to 40. The individual descriptions are given in Sections 58 to 68.

Advantageous features of the horizontal trap sampler are:

<u>a</u>. Relative simplicity of design and operation.

<u>b</u>. Wide range of adaptability to shallow and deep streams of all velocities.

<u>c</u>. Ability to sample close to the stream bed.

<u>d</u>. Positive closure of the sampler at the sampling point to prevent intermixing during the ascent.

Of the fundamental objections or adverse features discussed in Chapter IX, the following appear to be important in the instantaneous horizontal trap samplers:

<u>a</u>. The instantaneous action necessitates taking a series of samples from each sampling depth if average concentration is desired.

<u>b</u>. The non-removable sample container necessitates transferring the samples to other containers for shipment to the laboratory.

In addition, there is probably some disturbance to the flow of water caused by the external flap valve at the entrance. There is also the possibility that a decrease in turbulence caused by the constricted flow through the sampler would cause a deposit of some of the coarser sediment within the chamber and result in a sample of exaggerated sediment concentration.

Because of their ability to sample close to the stream bed, horizontal trap samplers are used extensively under conditions encountered in swift mountain streams where practically all the sediment is carried near the bottom.

36. Bottle type samplers--The most readily improvised sampling device for sediment investigations consists of an ordinary milk bottle, fruit jar, or other standard container with the necessary provisions for lowering to the sampling point. Individual samplers of this class are equipped with various appliances for opening and closing the container. Common samplers of this class are illustrated by Figs. 41 to 58 and are discussed individually and more completely in Sections 69 to 81.

The bottle type samplers are provided with an entrance for the sample varying in size from about 1/4 in. in diameter up to the regular milk bottle mouth. The air within the bottle, displaced by the inflowing sample, escapes through the mouth of the bottle producing a bubbling action or disturbance at the entrance. Because some time is required to fill the sampler after it is opened and because air bubbles escape through the water entrance, the bottle samplers are often referred to as "slow filling" or "bubbling" samplers.

It is probably an accidental property rather than a feature contemplated in the design that the slow filling action of the bottle type samplers results, to some extent, in a time-integrated sample. In most cases, however, it is doubtful if the time of filling is sufficiently long to secure a sample that averages with sufficient accuracy the fluctuating concentration. The time required for filling varies with the individual samplers and with the depth of sampling.

The principal advantageous features of the bottle type sampler are:

a. It is simple in design.

b. The sample containers are removable for shipment to the laboratory.

Bottle samplers with small openings are used in some cases to sample by the depth-integration method. They are operated to collect continuous samples throughout the stream depth and may be lowered to the bottom and opened, to fill while being raised to the surface, or left open to fill while being lowered and raised.

The objectional features listed and discussed in Chapter IX which are particularly applicable to the bottle type samplers are:

a. It causes excessive disturbance to the flow.

b. The filling rate varies, due to a difference in pressure inside and outside, especially if the sampler is opened after it is submerged.

c. Water from depths other than at the sampling point intermixes if the sampler is not provided with positive opening and closing devices.

d. It is unsuitable for sampling close to the bottom or in very shallow streams.

The disturbance at the mouth of the bottle, caused by the change in direction of flow and by the bubbling action of the escaping air, introduces errors of unknown magnitude.

Bottle samplers with containers of fixed volume which are opened after being submerged, are subject to a rapid initial filling rate until the internal and external pressures are equalized. Therefore, the rate of filling is not uniform during the sampling period, and the sample secured may be of incorrect composition, as described in Section 42. Although some samplers of the bottle type are opened and closed at the sampling point, there are several samplers in use which are opened at the desired depth and left open after filling. Others are always open. The result is that considerable mixing of the sample with water from above the sampling point may take place as described in Section 43.

The total height of a bottle sampler is generally greater than that of other types due to the upright position of the bottle and the weights which usually are attached below. This limits their use in shallow streams or other situations where it is necessary to sample close to the bottom. To allow the use of bottle samplers in deep streams, opening and closing devices are practically essential, but in general, these devices increase their resistance to stream flow.

37. Time-integrating samplers--The desirability of obtaining from a single sample of water-sediment a mean value of the fluctuating silt concentrations occurring at a single point has resulted in the development of several time-integrating samplers. In general, the sample containers are filled slowly and continuously over a period of time ranging from 10 to 60 sec. for the various samplers. Individual samplers of this type are described in Sections 82 to 90. The Rock Island time-integrating sampler, described in Section 91, collects a series of small instantaneous samples from a sampling point to comprise the average sample.

An important feature of most of the time-integrating samplers, distinguishing them from the ordinary bottle samplers which, in some respects, may also be considered slow filling and time-integrating, is that the sample intake and air exhaust tubes have been separated. The escaping air causes no disturbance to the inflow as the sampler is filled. The intake tube or orifice is pointed directly into the current, so as to eliminate a change of direction of the flow at the intake.

A time-integrating sampler fitted with an opening mechanism is lowered to the sampling position with the filling device closed, and if fitted with a closing mechanism it is closed before raising the sampler. In this manner, mixing the sample with water from other levels can be avoided. If the sampler does not have either an opening or a closing mechanism, the sampler is lowered to the sampling position and after being filled it is raised again as rapidly as possible, in order to reduce to a minimum intermixing of the sample with water from other layers. If the sample container is of the fixed volume type it is not practicable to lower the sampler fast enough to avoid considerable mixing of the sample with water from layers above the sampling point, particularly if this point is at considerable depth.

In the depth-integration method of sampling, which is extensively used at present, the time-integrating sampler is lowered to the bottom and raised again at a uniform rate, collecting the sample continuously throughout the stream depth. If the rate of transit is not too rapid, the pressure inside and outside the container will be balanced and the filling rate will be substantially a function of the stream velocity. A time-integrating sampler of the collapsible container type, with intake facing directly into the current, will have a rate of filling which is approximately proportional to the stream velocity and practically independent of the depth. This characteristic is highly desirable in a sampler operated by the depth-integration method. Furthermore, when used to take time-integrated samples, this type of sampler eliminates the uneven filling rate and attendant error in silt concentration of the sample which occurs in using a fixed-volume container, due to the presence of sub-hydrostatic pressures within the container when it is opened after being submerged.

38. Pumping samplers--The method of sampling in which the water is pumped from the desired sampling point has several advantageous features:

a. By directing the intake of the suction hose into the current and regulating the intake velocity it should be possible to obtain an undisturbed sample representative of the sediment concentration in the stream.

b. A specimen of any desired volume can be obtained.

c. By sampling over an extended time, the sample obtained will give an average value of sediment concentration.

The disadvantages of this system with equipment used heretofore, are:

a. The equipment is too bulky for portability and not adaptable to sampling from small boats or cableways.

b. The larger particles of suspended sediment tend to segregate and settle as the water is raised through the suction pipe or hose, which necessitates maintaining a velocity in the hose higher than the fastest settling rate of the sediment.

c. The velocity in the intake of the sampler must be regulated so as not to produce divergence, convergence, or change of direction of flow lines.

d. The resistance of the sampling hose to the current limits the velocities and depths in which the pumping samplers may be used.

e. The vertical distance from the water surface at which this type of sampler can be operated is limited by the height to which a sample can be raised by vacuum.

A common water lift pump has been used in some investigations, but in the more recent system, as illustrated by Figs. 70 to 73, a hand pump was used to produce a vacuum to lift the water into the sample container. A siphon was used to some extent in Sind, India, in which the desired siphon head was produced by lowering the discharge pipe to various depths into a deep sample container partially submerged in the stream. A noteworthy boat installation, consisting of a hand pump, sampling hose, and centrifuge for analyzing the samples, is described in Section 94.

39. <u>Photo-electric analysis</u>--A photo-electric method of investigating the suspended sediment concentration of streams as described by Jakuschoff (29) has been used by a few observers, but invariably it has been abandoned as impractical. In the application of the photo-electric cell to study the turbidity of water, a light source of constant intensity provides the beam which is passed through the suspension to the photo-electric cell. The intensity of an electric current through the cell, as indicated by a galvanometer, varies as the intensity of the light beam at the cell and is thus a measure of the turbidity or light transmitting properties of the suspension.

In the previous application of this method to the study of sediment concentration in streams, calibrations were made upon known samples to establish the turbidity-concentration relationship. The factors, other than sediment concentration, affecting the turbidity; namely, the properties of the suspended medium and the light beam, and the size, shape, color, and surface characteristics of the sediment particles, were assumed to remain constant during observations or between calibrations. The reliability of this assumption depends upon the nature of the stream and its sediment. Theoretically, both the concentration and size distribution of the sediment vary throughout a stream section so that a change in turbidity could not be attributed directly to a variation in one of these factors alone. Where the sediment is known to be composed entirely of fine particles and that it is more or less uniformly distributed throughout a stream, the method may be sufficiently reliable.

Because of the frequent calibration necessary and the questionable reliability, it is doubtful if the photo-electric method is sufficiently practical at present to replace a sampling program. It is possible, however, that it can be developed to indicate how often samples should be taken in a regular sediment investigation program.

IX. ADVERSE FEATURES OF SAMPLERS

40. Instantaneous sampling action--Samples which are collected by instantaneous horizontal or vertical samplers represent the concentration at the sampling point only for the instant of sampling. If the sediment concentration at the point is subject to rapid fluctuations, as is usually the case, a mean value based on only one instantaneous sample is of doubtful validity.

That these rapid fluctuations may be of appreciable importance is illustrated by the results of several field tests. These field tests, however, are representative of a range of sampling conditions sufficiently wide only to point out that the possible existence of the fluctuations should be considered. In a test conducted in the Mississippi River by the U. S. Engineer District Office, Rock Island, Illinois, several nearly instantaneous samples were collected simultaneously from the river surface at points spaced on a line parallel to the stream flow. The sediment concentrations were found to vary as much as 100 per cent between samples. The conditions of this test were quite normal and representative of numerous medium sized rivers.

Gontcharoff (29) conducted tests in the Kuban River, Russia, in which he collected a series of instantaneous surface samples at 5-min. intervals and a series of bottom samples at 10-min. intervals. The results showed variations of 16 per cent from the mean concentration of the surface samples, and variations of as much as 60 per cent from the mean concentration of the samples obtained near the bottom.

41. Disturbance of flow characteristics--It is readily apparent

from a study of the various samplers in use that, in varying degrees, they change the flow characteristics in the immediate vicinity of the sampling point. These disturbances or changes in direction of flow or velocity may cause segregation of suspended sediment from the water and the samples collected will not represent the sediment content of the stream. Because the sediment particles possess greater density and momentum, they will tend not to follow the water in its changes of direction or velocity. Sufficient data or analytical methods are not available at the present time to permit a satisfactory evaluation of this possible source of error. Nevertheless, it is obvious that certain types of samplers, or their modes of action, do affect the flow characteristics.

The vertical pipe, bottle, and certain of the time-integrating samplers, cause the water to undergo an acute change of direction in passing through or into the sampler. The flow through the sampling tube of the instantaneous horizontal trap sampler is usually considered to be practically undisturbed, but it may be affected to a considerable extent by the flap valves, or any other portion of the sampler protruding ahead of the sampling tube. Some instantaneous vertical trap samplers are designed to minimize the disturbance of flow in the sampling zone with varying degrees of success. The most obvious disturbance, considering all types of samplers, occurs at the mouth of the ordinary bottle sampler where air bubbles must escape through the inflowing sample.

Even the samplers in which the intake conditions have more nearly approached the ideal, with intakes facing directly into the current, may cause changes of flow characteristics sufficient to introduce error in the sample. If the velocity into the intake is greater or less than the velocity of approach, the flow will converge or diverge and consequently the sediment particles will tend to separate from their respective flow lines. This effect probably increases with increasing particle size. The effect of a sampler upon the surrounding stream flow will be less serious if the intake is placed ahead of the sampler proper.

When sampling near the stream bed, currents may be set up due to the presence of the sampler, which will cause mixing or raising of bed material into suspension so that it may enter the sampler and introduce appreciable error in the sample. This is a factor to consider in the field operation as well as in the design of a sampler.

42. Filling due to initial pressure differential--Any sampler with a sample container of fixed volume, which is closed while being lowered to the sampling point has an air pressure inside which is less than the hydrostatic pressure on the outside surface. Thus, when the sampler is opened water rushes into the container at a very rapid rate compressing the air until the static pressures are equalized. The pressure differential and, consequently, the rate of inflow and volume of sample collected during this initial period are dependent upon the depth of submergence. The time required for pressure equilibrium to take place depends upon many factors and, no doubt, varies with the different samplers, but there is reason to believe that it usually takes less than one second. After the pressures are equalized, the remaining capacity of the sampler fills slowly as the air escapes and is replaced by the water.

The proportion of the sampler capacity which will be filled during this initial period can be computed on the basis of Boyle's law, as it depends upon the change in volume of the inclosed air when compressed by the water pressure at the sampling point. For example, at a depth of 33 ft., where the absolute water pressure is two atmospheres, the air will be compressed to one-half its original volume and the sampler will be filled to one-half of its original capacity when the pressures are equalized. At a depth of 66 ft. the absolute water pressure is three atmospheres and the air in the sampler when opened will be compressed to one-third the original volume; two-thirds of the sampler volume will be filled by the sudden inrush, leaving only one-third to receive a sample at a uniform rate.

This initial inrush occurs in all of the bottle type, and in all of the time-integrating type samplers except those which collect the sample in a collapsible container. It occurs not only when such samplers are closed while being lowered to the sampling point and then opened, but also in fixed container samplers with small port openings, which are lowered rapidly to the sampling point with the filling port open. This practice is often used on the assumption that the inflow during the descent is negligible. It is believed that in most samplers, this filling takes place so rapidly that by the time a sampler has been lowered to a measuring point 33 ft. below the surface the container will be half filled, even if it were lowered quite rapidly.

The following effects of this initial inrush, or pressure differential filling, are obvious:

<u>a</u>. A large part of the sample is taken in a very short time and the remainder over a longer interval, resulting in a sample which does not represent the average concentration existing during the sampling period.

<u>b</u>. The initial filling may be so rapid that the stream lines of the flow entering the sampler are abruptly deflected,

which may cause a separation of the water and sediment, and thus give a sample which indicates less than the correct quantity of sediment.

c. When an open sampler is lowered into the stream an appreciable mixing of the sample with water from above the sampling point will take place.

43. Mixing of sample with water from above the sampling point-- Samplers of the vertical trap type collect samples which contain, to a greater or lesser extent, sediment from above the level of the sampling point, since when the sampler is lowered, the water meets with some resistance from its valves and in flowing through the vertical tube. Therefore, some water from higher layers is carried along with the sampler as it is lowered, and is entrapped when the sampler is closed. The extent to which this intermixing takes place is proportional to the resistance to the flow through the tube, but no data are available from which the magnitude of this mixing can be determined. Various samplers of the bottle and time-integrating types, used to collect point samples, are not provided with opening and closing devices. Others are provided with devices for opening only. In either case, the assumption is made that errors introduced due to the inflow into the sampler from points other than the desired sampling point are negligible. In using these samplers they are lowered and raised as rapidly as practicable to minimize this effect. As indicated in the discussion of initial filling due to pressure differential in Section 42, if such samplers are of the fixed volume container type, the water from higher levels will flow in rapidly as the sampler is lowered, so that, if the depth of the sampling point is considerable, an appreciable part of the sample is collected from higher layers.

Considerable mixing may take place by flow into certain types of samplers, even after they are filled, if they are not provided with closing devices. This is illustrated by a simple test conducted by Mr. C. S. Howard of the U. S. Geological Survey (24). An ordinary bottle sampler was filled with clear water, closed, and lowered to the sampling point. There it was opened, and raised quickly to the surface. Some of the samples were found to have sediment concentration as high as 25 per cent of the stream concentration.

The possibility of intermixing in horizontal trap type samplers is probably eliminated if the valves are tight fitting and there is relatively unobstructed flow through them for some time prior to sampling.

44. Inability to sample close to the bottom--It is evident that samples must be taken close to the bottom of a stream if an accurate determination of the sizes of the material carried is to be obtained. In most streams the greater part of the coarse material is carried along very close to the bottom. Unless a sample is taken in this zone, these coarse sizes may be almost entirely absent from the sample. In many problems, this class of material is of primary importance and failure to secure accurate samples of it may lead to very unsound conclusions.

45. Non-removable sample containers--In a number of the bottle-type samplers, and in practically all of the instantaneous trap samplers, the sample container is an integral part and not removable. This necessitates transferring the samples to other containers for transporting to the laboratory. In this transfer there is a possibility of losing some of the sediment as it may settle out and adhere to the original container.

Although the amount of sediment lost in this manner may be very small and almost unnoticeable, it may in some cases be a considerable percentage of the total sediment in the sample.

46. Limited adaptability--An adverse feature of existing samplers is that they have, in varying degrees, limited adaptability to field conditions. The degree depends to a large extent on the basic principle of action, the exterior design, and the necessary appurtenances, including the suspension and control cables. Many samplers are suitable only for use in very large streams and others to very small streams, with few, if any, suitable for both.

Bulky, unstreamlined samplers, exposed and complicated operating mechanisms, or extra suspension or operating cables, may cause excessive resistance in swift currents. This resistance, or drag, causes a sampler to drift downstream and makes location at the desired sampling point more difficult. Weights, added to decrease the drift of a sampler, increase the difficulty of handling, and when suspended beneath the sampler they interfere with sampling close to the stream bed.

X. DESCRIPTION OF INDIVIDUAL SAMPLERS

47. Humphreys and Abbott keg sampler--The Humphreys and Abbott keg sampler was used for suspended sediment investigations conducted by Professor Forshey in 1851 in the Mississippi River at Carrollton, Louisiana. The sampler consisted of a small, weighted keg, equipped with a large flap valve in each end. The flap valves were actuated by the water reaction, opening upward as the sampler was lowered and closing as the sampler was stopped at the desired sampling point. Thus, the water-sediment passed through the keg until the valves closed at the sampling point.

Other samplers, differing from this original keg sampler in details of the sample container and type of valves, but operating on the same principle, have been used extensively in past investigations.

48. Johnson vertical trap sampler--The sampler, illustrated in Fig. 9, was designed by Mr. J. B. Johnson for the suspended sediment investigations in the Mississippi River at Helena, Arkansas, in 1879. It consisted of a vertical, galvanized iron cylinder to which were hinged two lids opening outward from the ends of the cylinder. Prior to sampling, the lids were held in the open position by a catch mechanism. When a trigger arrangement below the sampler touched the stream bed, the lids were released and they closed upon the ends of the sample cylinder under the action of heavy rubber bands connecting them.

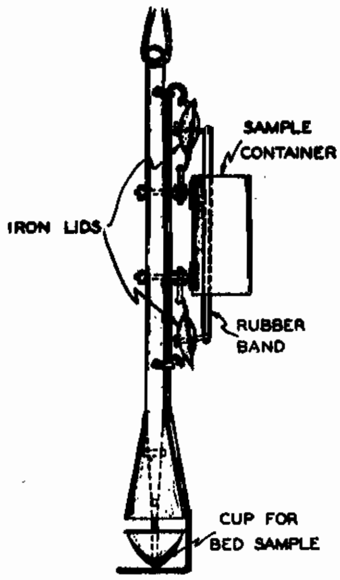


Fig. 9--Johnson vertical trap sampler.

The Johnson sampler, featuring a completely open sample cylinder, allowed free passage of the water during the descent to the stream bottom. The Humphreys and Abbott keg sampler, the earliest design of the same type, was not satisfactory because the valves in the ends of the sampler container restricted the flow of water through the sampler.

49. New Orleans District, U.S.E.D., vertical trap sampler--The First New Orleans District of the U. S. Engineer Department developed the vertical trap sampler, shown in Fig. 10, for use in recent sediment investigations in that district. The sampler consists essentially of a 2-in. pipe, 14 in. long, suspended vertically with a rubber ball valve at each end. The balls are held in the open position against the tension of springs within the pipe by a trigger catch mechanism and are released to close the pipe at the desired sampling depth when a weight, dropped down the suspension cable, falls upon the trigger.

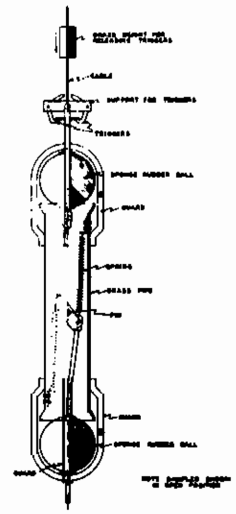


Fig. 10--New Orleans District, U.S.E.D., vertical trap sampler.

50. Vicksburg District, U.S.E.D., vertical trap samplers--The Vicksburg U. S. Engineer District in recent investigations has used and experimented with samplers of the type shown in Fig. 11. The samplers consist of sections of pipe, suspended in a vertical position, provided with flap valves which are operated by the water reaction. The valves, as in the original Humphreys and Abbott keg sampler, are held open by the water reaction as the sampler is lowered and are closed instantaneously

when downward movement of the sampler ceases. The water-sediment sample is trapped in the pipe at the time the valves are closed.

Other samplers of the same basic design have been used to some extent in recent sediment investigations but are not in general use at the present time.

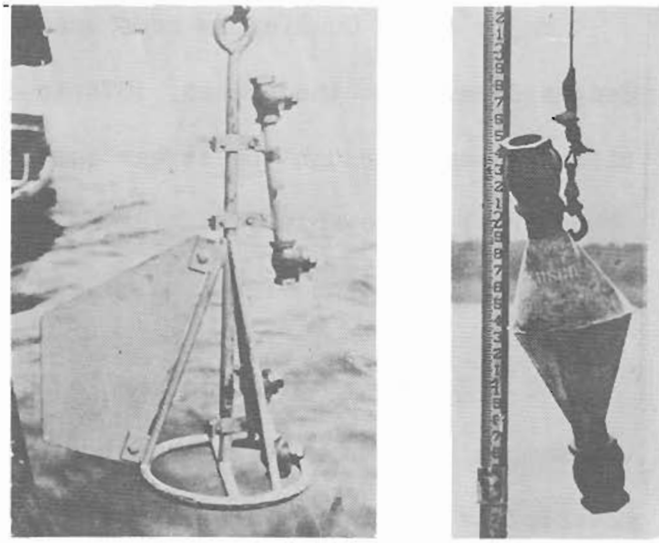


Fig. 11—Vicksburg District, U.S.E.D., vertical trap samplers.

51. Riesbol pipe sampler--The Riesbol sampler, shown in Fig. 12, was developed by Mr. H. S. Riesbol of the Watershed and Hydrologic Studies Section of the U. S. Soil Conservation Service. It consists essentially of a section of 2-in. pipe, of a length somewhat greater than the maximum sampling depth, mounted in a simple frame that guides the pipe vertically and holds a base plate on which the lower end of the pipe can be sealed. In using the sampler the guide is placed in the stream with the base plate resting on the bottom and the pipe is raised out of the water. The pipe is then thrust downward through the water and seated upon the base plate cutting a water-sediment sample from the entire depth traversed. The sampler is considered to be practically instantaneous in action and the sample obtained an average from the entire depth of the stream.

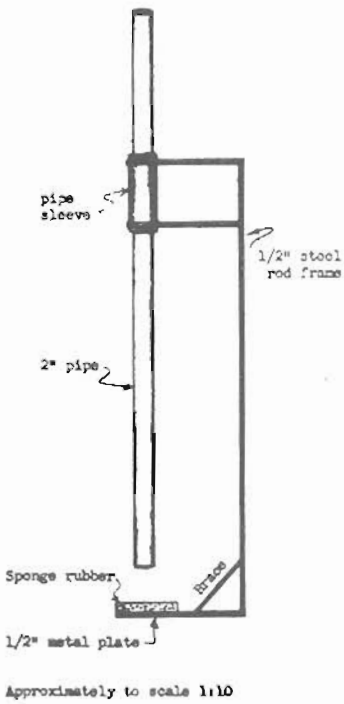


Fig. 12--Riesbol pipe sampler.

Major Allen Cunningham made use of this method of sampling in the Ganges Canal in the years 1874 to 1879, thrusting a 12-ft. section of pipe downward through the stream section. The pipe was closed at its lower end by a movable lid actuated by a strong spring. Complete details regarding the action of the valve are not available.

52. Eckman sampler--In the Eckman sampler, illustrated in Fig. 13, the sample is trapped in a vertical cylinder between a top and a bottom cover plate. While being lowered to the sampling depth the cylinder is suspended above the lower plate and the upper plate is suspended several inches above the top of the cylinder. When the catch mechanism is released, by dropping a messenger weight down the suspension cable, the upper lid drops down upon the top of the cylinder and, simultaneously, the upper lid and cylinder together drop down upon the lower lid, thus trapping the sample in the cylinder. A weight below the sampler is suspended from the upper lid to actuate the downward movement of the top lid and the cylinder.

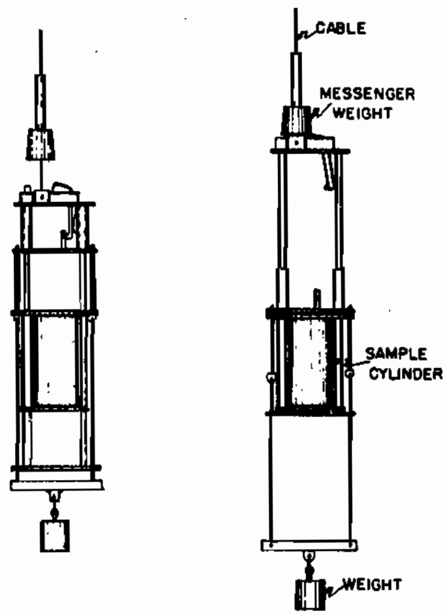


Fig. 13--Eckman sampler.

53. Modified Foerst sampler--The modified Foerst sampler, shown in Fig. 14, is being used by the U. S. Bureau of Reclamation in present silt density investigations in Lake Mead, the reservoir of Boulder Dam. It was made by the Foerst Mechanical Specialties Company of Chicago,

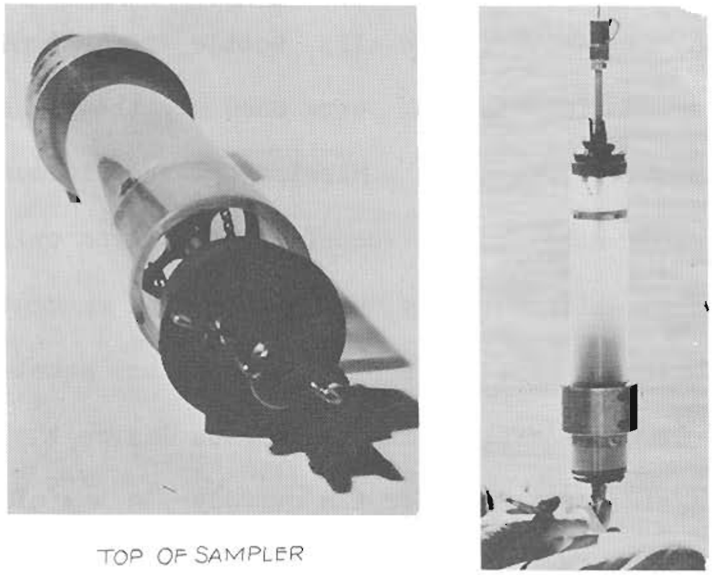


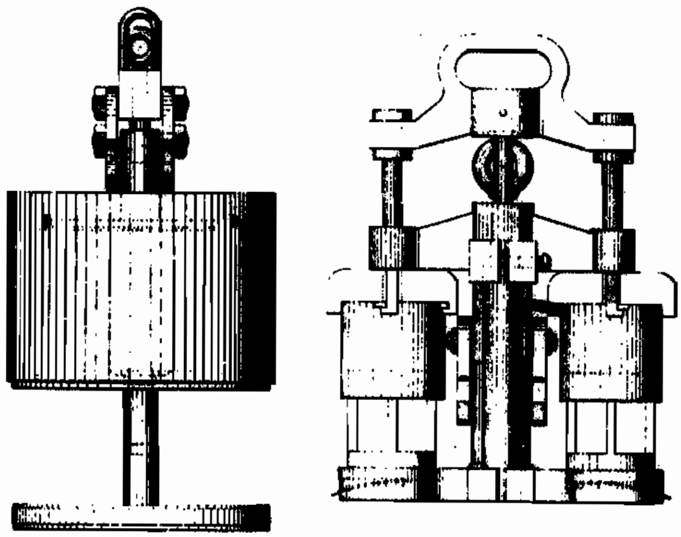
Fig. 14--Modified Foerst sampler.

Illinois, and modified for the specific conditions of Lake Mead.

The sampler consists of a vertical cylindrical sample container of transparent lucite which slides upon a vertical concentric shaft. In the open position the cylinder is suspended 2 in. above the bottom stopper which is permanently attached to the lower end of the guide shaft. The cylinder is held in this position by a chain attached to the upper stopper which, in turn, is held at the top of the guide shaft by a catch mechanism so that the upper stopper is 2 in. above the top of the cylinder. In this position the sampler is lowered to the sampling depth, the water being free to pass through the container. At the desired depth, a messenger weight dropped down the suspension cable trips the dogs which hold the upper stopper. The stopper and the cylinder fall simultaneously, sealing the lower end of the cylinder upon the bottom stopper and closing the top of the cylinder with the upper stopper, thereby trapping the sample. A lead band may be placed around the cylinder or weights may be suspended below the sampler when needed.

54. Slip bottle samplers--The slip bottle instantaneous vertical trap samplers, shown in Fig. 15, were used by the Mississippi River Commission for observations in the Mississippi and Missouri Rivers from 1879 to 1881. The slip bottle consists of an iron cylinder 8 in. in diameter 6 in. long, which moves along a vertical concentric rod. Two iron disks are fastened to the rod separated a distance equal to the height of the cylinder, the upper disk acting as a piston inside the cylinder, and the lower disk acting as a seat for the cylinder in the closed position.

Prior to sampling, the cylinder is supported in the open position by a catch mechanism. When the sampler has been lowered to the desired sampling point, the cylinder is released by a pull on an auxiliary line and falls upon the lower disk to trap the sample.



Single Double

Fig. 15--Slip bottles, instantaneous vertical samplers.

The double slip bottle, a later design, has two separate and identical bottles of smaller capacity. The sample is trapped in small rectangular slots of a modified piston. Instead of having two disks on a common axis, the modified piston is a single unit of height equal to that of the cylinder with two vertical rectangular slots through the piston at right angles to each other which allows the passage of water when the cylinder is raised and contain the trapped sample when the cylinder drops down over the piston. The capacity of the slip bottle sampler was reduced from 1/2 gallon to about 1/4 pint by the change in design.

55. <u>Beach and Shore Erosion Board sampler</u>--The Beach and Shore Erosion Board sampler, shown in Fig. 16, consists essentially of a cylindrical sample chamber with a piston type valve mechanism for opening and closing the intake ports into the chamber. The valve mechanism consists of a piston within the sample chamber connected by a rod to another piston above the sample chamber. The upper piston, with the attached valve, is operated by air pressure which forces it down against the

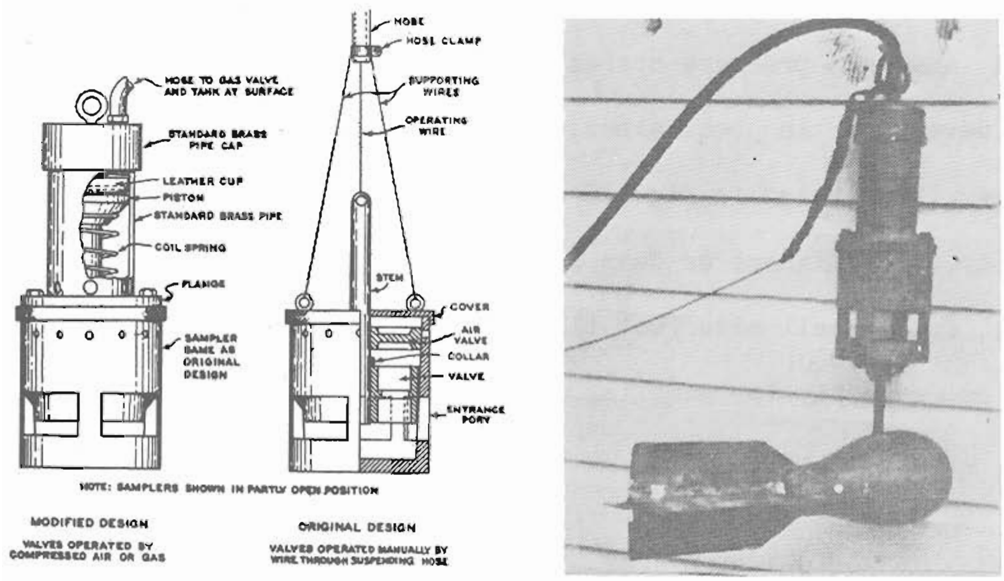
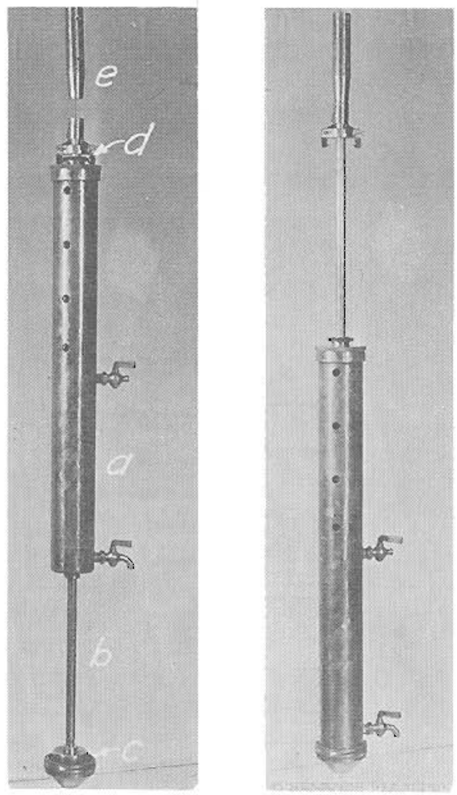


Fig. 16--Beach and Shore Erosion Board instantaneous vertical sampler.

compression of a coil spring. The air pressure is supplied to the sampler through a hose from a pressure tank at the surface. Prior to sampling sufficient air pressure is maintained above the upper piston to keep the valve down and the ports of the sampler closed. At the desired sampling point, the air pressure is released and the piston is raised by the action of the coil spring, allowing the water-sediment sample to enter the chamber through the open ports. After a few seconds interval the air pressure is again applied to the upper piston, forcing it down and enclosing the sample in the chamber.

The sampler as originally designed was the same in principle and action but was operated manually instead of with air pressure. The valve was lifted to open the sampler by pulling on an auxiliary or operating line connected direct to the piston rod and closed when the line was released.

Samplers of this design, for both manual and gas pressure operation, have been developed in two sizes; the large size as illustrated in Fig. 16 of 740 cc. capacity for offshore or deep stream sampling; and a small size (not illustrated) of 85 cc. capacity for sampling in shallow water.



Open Closed

Fig. 17--New Orleans Sewage and Water Board instantaneous vertical sampler.

56. <u>New Orleans Sewage and Water Board sampler</u>--The sampler, shown in Fig. 17, was developed by the Sewage and Water Board of New Orleans, Louisiana, and is used in the present investigations of the Second New Orleans U. S. Engineer District. It consists principally of a sample cutter <u>a</u> of $2\frac{1}{2}$-in. brass pipe, 25 in. in length, which moves vertically upon a 40-in. length of 5/8 in. brass rod <u>b</u>. To the lower end of the rod is attached a base <u>c</u> which acts as a seat for the cylinder in the closed position. Approximately 12 in. above the base

plate, attached to the rod and machined to fit the inside diameter of the cylinder is a piston that guides the cylinder and acts as an upper valve. A trigger catch mechanism d at the top of the rod supports the sample cylinder preparatory to sampling. At the desired sampling depth the cylinder is released by a messenger weight e dropped down the suspension cable, falls of its own weight, seats upon the lower base, and thereby traps the water-sediment sample. Two air cocks are provided in the side of the cylinder to facilitate draining the sample into a container for shipment to the laboratory.

57. Eakin sampler--The Eakin sampler, shown in Fig. 18, was designed by Mr. H. M. Eakin for the Memphis U. S. Engineer District for use in the Mississippi River, and is now used extensively by the U. S. Soil Conservation Service and other agencies. It consists essentially of a cylindrical cutter tube c which slides down over an upper disk or piston b and seats upon a lower disk a to trap the water-sediment sample. Prior to sampling, the cutter tube is held in the raised or open position by a catch mechanism, and, when released by a messenger weight dropped down the suspension cable, it snaps downward under the action of a heavy coiled spring housed in the sampler.

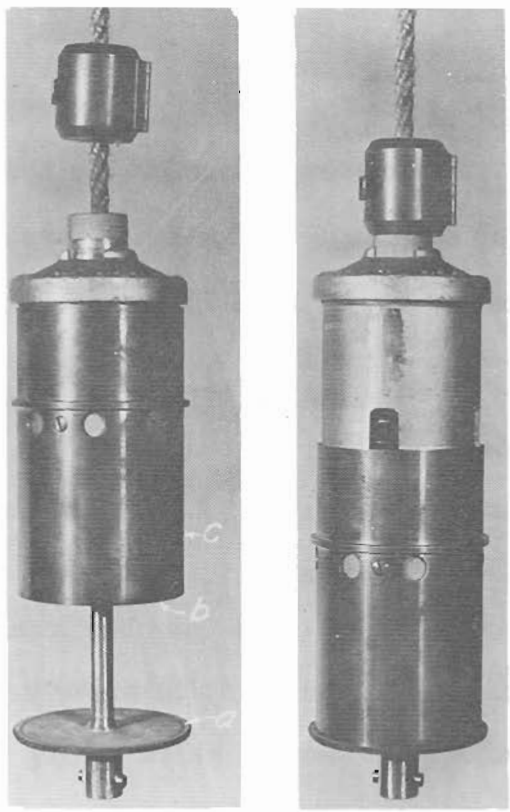
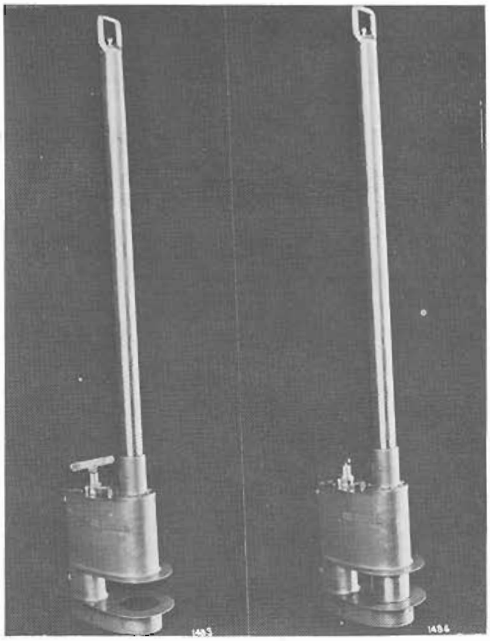


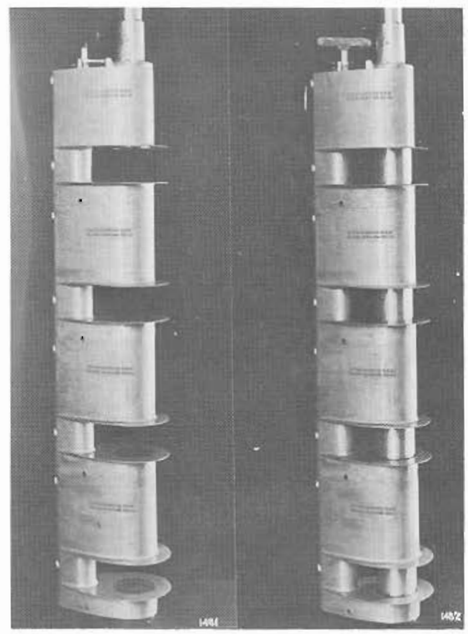
Fig. 18--Eakin instantaneous vertical sampler.

A more recent design of the Eakin sampler, shown in Fig. 19, has been evolved from extensive experimentation by the U. S. Soil Conservation Service at the California Institute of Technology. This sampler is streamlined to reduce its drag or resistance to stream flow.



Open Closed
Fig. 19—New Eakin single sampler.

It is altered further to reduce obstruction and disturbances at the actual point of sampling. A multiple sampler of the same type is illustrated in Fig. 20.



Open Closed
Fig. 20—New Eakin multiple sampler.

58. Leitz horizontal sampler—The Leitz sampler, shown in Fig. 21, has been used by Mr. C. T. Johnston and was described by him in a report, "U. S. Irrigation Investigations for 1900" published by the U. S. Department of Agriculture. The sampler consists primarily of a brass cylinder 1 ft. in length and 3 in. in diameter. The cylinder is closed at both ends by disk type doors which swing on a horizontal shaft parallel to the axis of the cylinder. Prior to sampling the doors are held in the open position by small rods which protrude beyond the ends of the cylinder. When

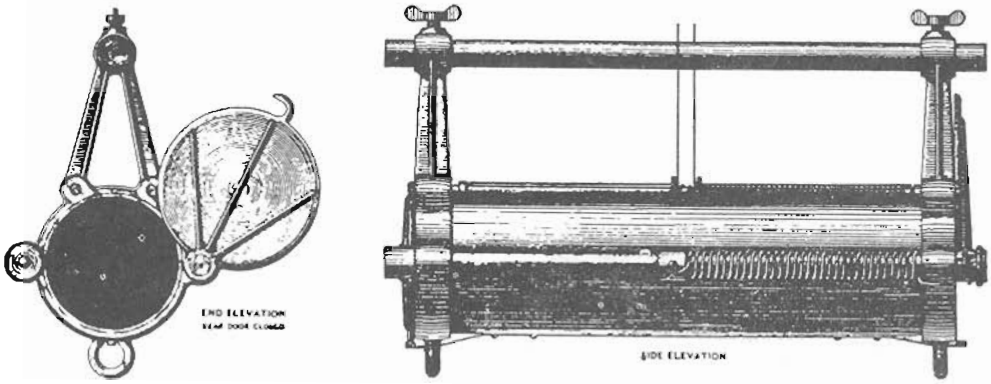


Fig. 21--Leitz horizontal sampler.

the sampler is at the desired sampling point a pull on an auxiliary line releases the rod-catches allowing the doors to close quickly and the sample is trapped within the cylinder. The swinging doors have not proved to be entirely satisfactory and the sampler is not used in present day investigations, but it is of historical value.

59. <u>Miscellaneous horizontal trap samplers</u>--Numerous samplers of the horizontal trap type have had extensive use in sediment investigations. They consist essentially of a horizontal cylinder or box through which the water-sediment is allowed to flow until the sample is trapped by valves which are closed suddenly on the ends of the cylinder. A number of these samplers will be described with a brief discussion of their individual valve mechanisms.

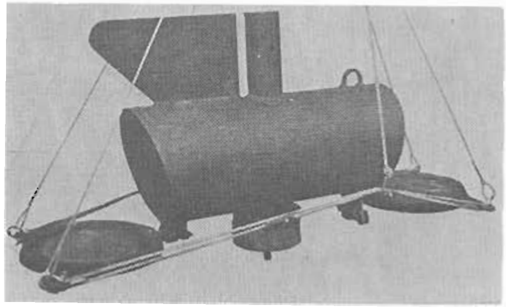


Fig. 22--Modified Collet horizontal sampler.

The modified Collet sampler, shown in Fig. 22, which has been used by the Port of Bordeaux Authority, consists of a horizontal container attached to a rigid vertical rod. Flap valves open downward, remaining in the open position prior to sampling. They are closed against the ends of the sample container and held there by control lines from the surface.

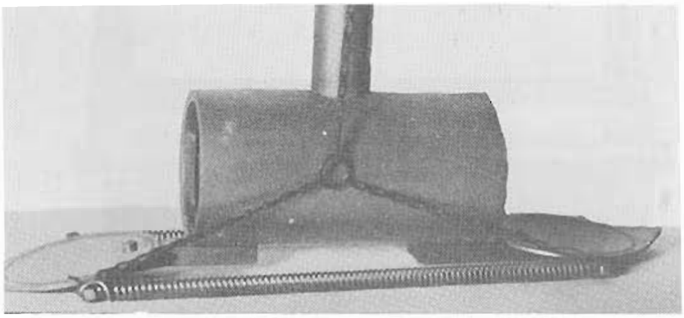


Fig. 23--Hjulstrom horizontal sampler.

The Hjulstrom sampler, shown in Fig. 23, used by Mr. Filip Hjulstrom in his studies of the River Fyris, Sweden, is a tubular container attached with axis normal to a section of pipe or handle, and is provided with flap valves hinged at the bottom side of the cylinder. The valves are held in the open position by tension springs connecting them and are closed by the springs upon being tripped by a pull on the operating chain.

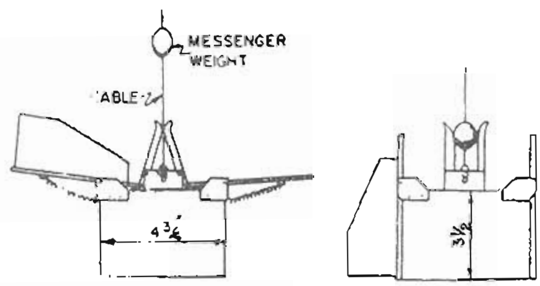


Fig. 24--Swedish horizontal sampler.

The Swedish sampler, shown in Fig. 24, is described by Jakuschoff as having a sample container of rectangular section with the end flap valves hinged at the top and held in the open position by a trip mechanism until released by a messenger weight.

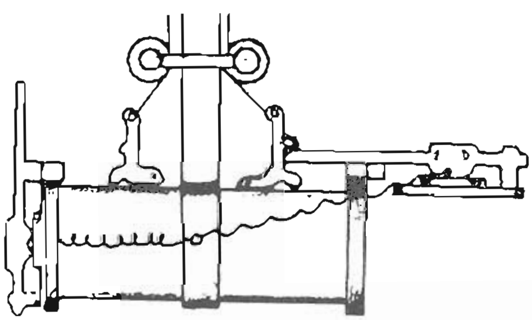


Fig. 25--Jaukowsky horizontal sampler

The Jaukowsky sampler, shown in Fig. 25, as described by Jakuschoff (29), is an open horizontal cylinder provided with flap valves hinged at the top. The valves are held in the open position by hinged catches which, when released by a

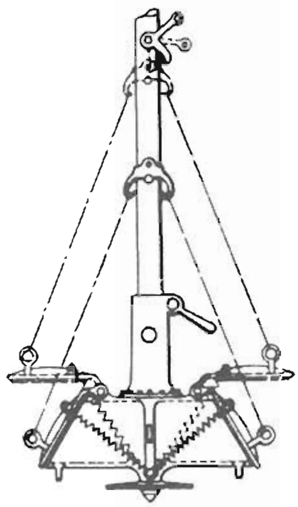


Fig. 26--Italian horizontal sampler.

pull on auxiliary lines, allow the valves to close.

The Italian horizontal sampler, shown in Fig. 26, is used by the Hydraulic Authority of Venice, Italy. The horizontal cylindrical sample container is attached to a rigid vertical handle. The flap valves, hinged to the top of the container, are connected by lines to a sleeve which slides upon the suspending handle. The valves are held in the open position against tension of coil springs when the sleeve is held in the upper position by a hinged catch. Upon release of the catch, by a pull on an auxiliary line, the sleeve is allowed to fall and the valves are closed tightly upon the sloping ends of the sample container.

The sampler used by the Swiss Federal Authority, of Bern, Switzerland, shown in Fig. 27, consists of a horizontal sample container of rectangular section. It is attached to a rigid handle by a pin connection so that the sampler may be easily tilted for emptying its sample. The flap doors at the ends of the sample container are hinged at the top and remain in the closed position except when held open by tension on auxiliary lines.

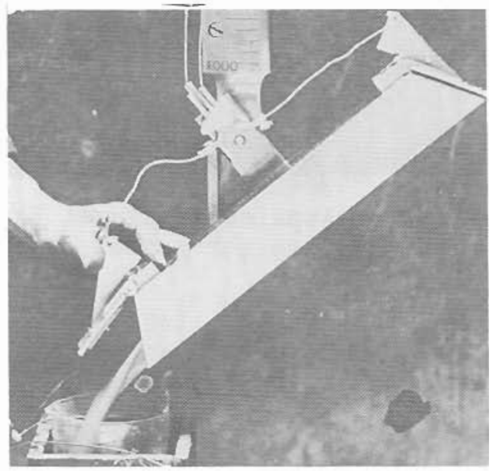


Fig. 27--Swiss Federal Authority horizontal sampler.

A horizontal trap sampler, illustrated in Fig. 28, used by the South Pacific U. S. Engineer Division, has a horizontal cylinder with weights and guide fins attached below. The sampler is suspended by two separate lines connected through a toggle lever system to flap valves at the ends of the cylinder. The line used for lowering the sampler holds the flap valves open and the line used for raising the sampler holds them closed tightly over the ends of the cylinder.

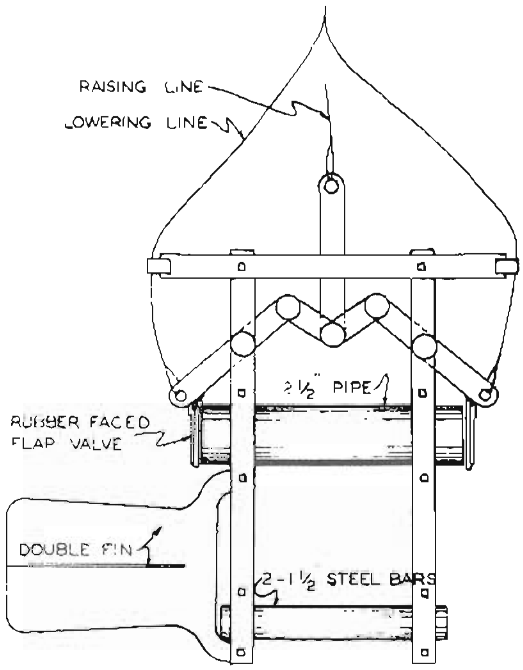


Fig. 28--South Pacific Division, U.S.E.D., horizontal sampler.

The Appalachian Forest Experiment Station sampler, shown in Fig. 29, is a rectangular box rigidly attached to a long handle. The open ends are equipped with doors which are hinged at the top and held in the open position against the tension of two springs. When the trip mechanism is released by a pull on an auxiliary line, the valves are closed quickly by the springs.

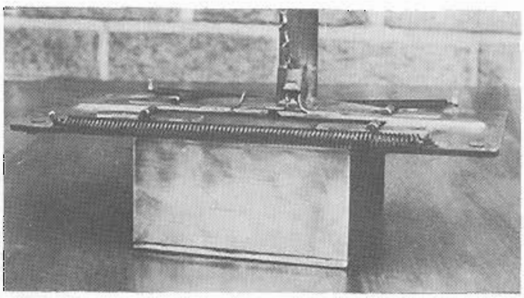


Fig. 29--Appalachian Forest Experiment station horizontal sampler.

60. <u>Sind sampler</u>--The Sind sampler, shown in Fig. 30, was developed in the Province of Sind, India, for trapping undisturbed water-sediment samples. It consists of a rectangular horizontal conduit with semicircular

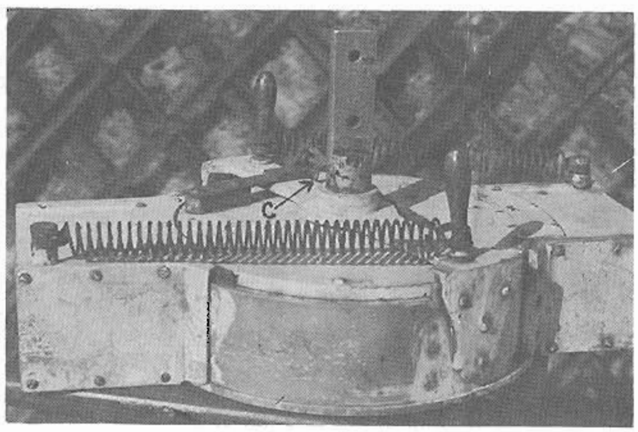
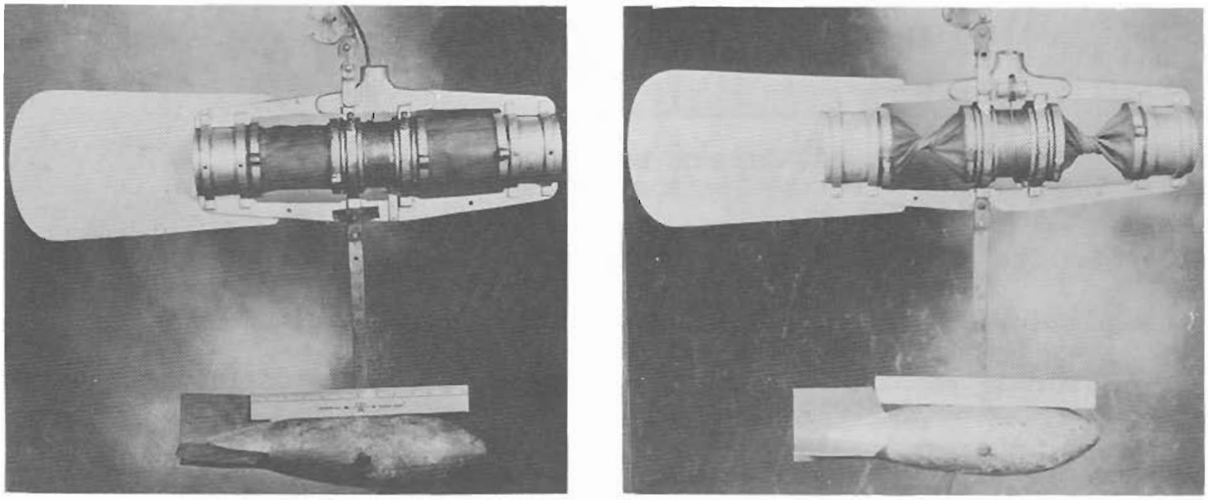


Fig. 30--Sind sampler.

band type doors housed in the sides. Prior to sampling, the doors are held in the open position by a catch against the tension of coil springs. A trip mechanism, released by a pull on an auxiliary suspension line, allows the doors to rotate and close the ends of the conduit.

61. Tait-Binckley sampler--The Tait-Binckley sampler, shown in Fig. 31, was designed by George S. Binckley and C. E. Tait of the Bureau of Public Roads to trap instantaneous samples from relatively undisturbed stream flow in sediment investigations in canals of the Imperial Valley.



Sample chamber open. Sample chamber closed.

Fig. 31--Tait-Binckley sampler.

The sampler consists essentially of three cylindrical metal tubes of equal diameter mounted coaxially on line in a horizontal metal frame. The middle tube which is the sample container, is mounted in the frame in bearings so that it is free to rotate about its axis and is connected to the two rigidly mounted end cylinders by sections of thick rubber tubing. To trap the sample, the middle section is rotated by pulling on an auxiliary line wound around that section, thus twisting the rubber sections and sealing the water-sediment sample in the middle section.

62. Smetana sampler of the Czechoslovakian Government--The Smetana suspended sediment sampler, shown in Fig. 32, is suspended directly below a streamlined current meter. One relatively compact, streamlined unit thus furnishes both velocity and sediment measurements. The sampler consists of an open horizontal cylinder which is closed by means of flap

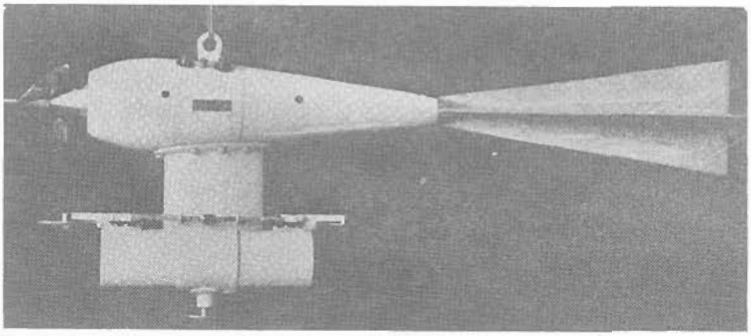


Fig. 32--Smetana sampler and current meter of the Czechoslovakian Government.

valves. The sampler is unique in that the flap valves are held open by a fuse of soluble salt and close instantaneously when the fuse is dissolved. About 3 min. is required for the fuse to break, allowing sufficient time for the sampler to be lowered to the depth of sampling.

63. Tennessee Valley Authority horizontal samplers--The Tennessee Valley Authority devised the sampler, shown in Fig. 33, for use in a wide variety of conditions. It consists of a horizontal cylinder cast inside a brass weight with a flap valve hinged just above the opening at each end. It is suspended about a horizontal axis normal to stream flow which permits the sampler to point directly into the current irrespective of down-stream drift. The valves are held open by a simple

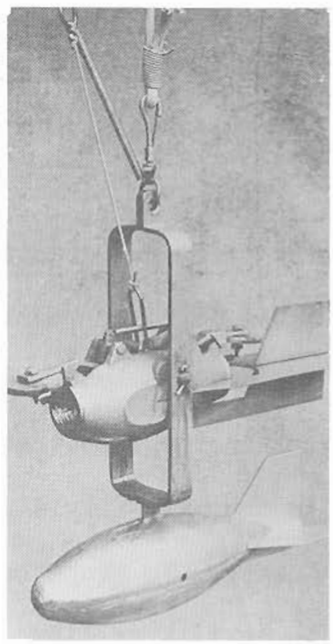
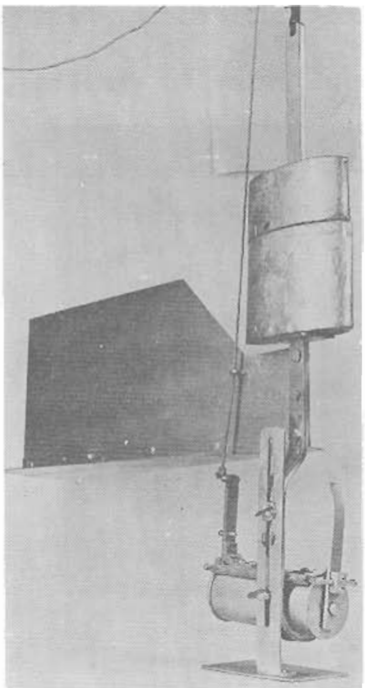


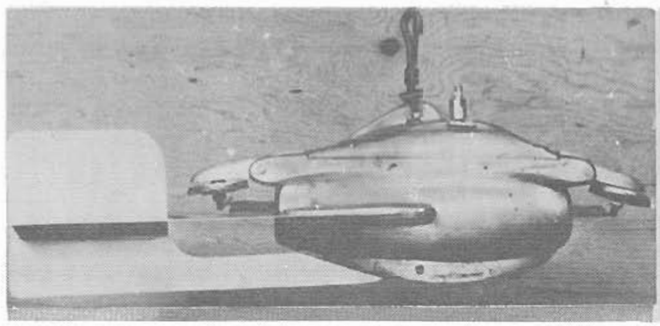
Fig. 33--T.V.A. sampler.

catch mechanism on top of the body, which can be released by a pull on an auxiliary line. A spring through the sample tube closes the valves instantaneously and holds them closed. The sampler has sufficient weight for ordinary conditions in shallow rivers. However, additional weights can be suspended below the sampler when needed.

The sampler, shown in Fig. 34, is an early design used by the Tennessee Valley Authority and Fig. 35 shows a later development. The latter is streamlined and has an entirely enclosed trip mechanism. Plates may be added to the bottom to aid in sampling near the stream bed or weights may be added if needed.



Early design.
Fig. 34--T.V.A.sampler.



Side view.

Front view.

Fig. 35--T.V.A. sampler, streamlined design.

A lightweight adaptation of the early design is shown in Fig. 36. Without the weight shown this type is particularly advantageous in shallow streams and for sampling near the stream bed.

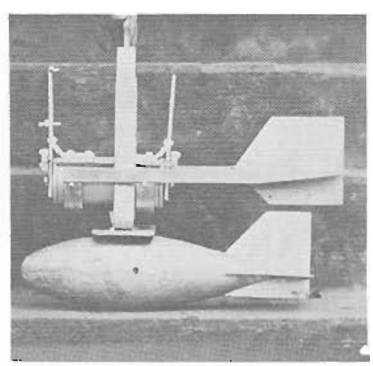
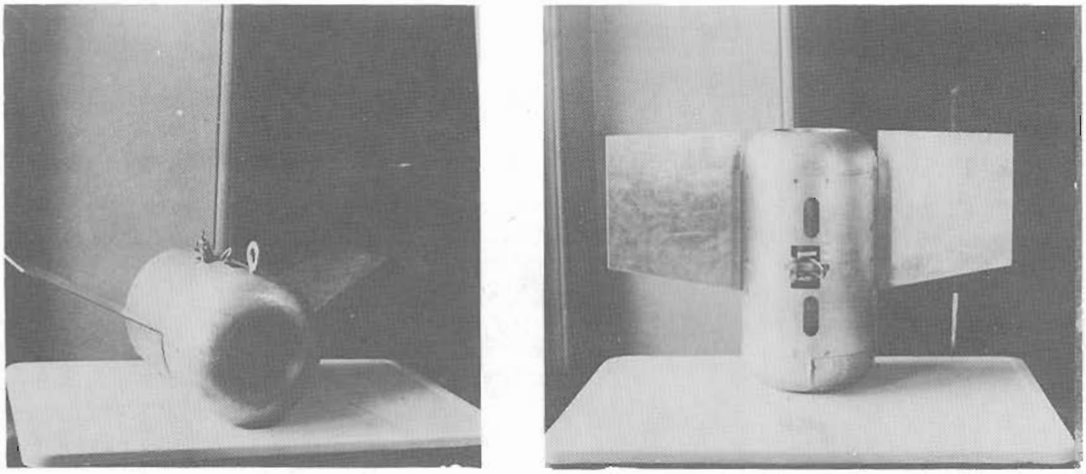


Fig. 36--T.V.A. sampler, lightweight design.

64. <u>Allegheny horizontal sampler</u>--The Allegheny sampler, shown in Fig. 37, was designed by Mr. H. P. Fry at the Allegheny Forest Experiment

Station of the U. S. Department of Agriculture. The sampler consists of a horizontal cylinder, encased in a streamlined shell and equipped with a rubber faced butterfly valve near each end. The valves, mounted within the cylinder on vertical axes, are actuated by a long coil spring which is connected to pulleys at the top of each valve axis. Prior to sampling,



End view. Top view.

Fig. 37—Allegheny horizontal sampler.

the valves are turned parallel to the axis of the cylinder and held in the open position, against the tension of the spring, by catches on the pulleys. When the catches are released by an auxiliary line, the valves rotate to the closed position, perpendicular to the axis of the cylinder.

The cylinder and the entire valve mechanism are completely encased in the streamlined shell, the bottom of which may be loaded with lead shot to provide the necessary weight. Guide vanes attached to the sampler orient it with the current.

65. <u>Vicksburg District, U.S.E.D., horizontal sampler</u>--The sampler developed and used by the Vicksburg U. S. Engineer District, as shown in Fig. 38, consists essentially of a 1-in. brass pipe through the center of

a streamlined weight. The pipe is provided with a plunger type valve at each end which are closed by the weight of the sampler as its base plate contacts the stream bed.

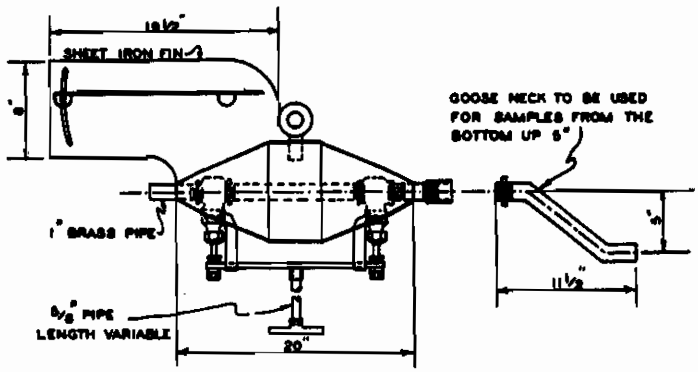


Fig. 38--Vicksburg District, U.S.E.D., horizontal sampler.

The distance from the base plate to the sample tube and, consequently, the height of sampling point above the stream bed, is variable up to about 5 ft. by the use of extension pipes of various lengths. A goose-neck extension for the sample pipe is provided which permits taking samples adjacent to the river bottom.

A later design of this sampler makes it applicable for sampling at any depth in a stream. For sampling near the bottom the sampler is used as described above, but for points more than 5 ft. above the river bottom it is inverted and a small weight is dropped down the suspension line to close the valves and trap the sample.

66. <u>Vicksburg District, U.S.E.D., horizontal toggle sampler</u>--An instantaneous sampler, shown in Fig. 39, was developed by the Vicksburg U. S. Engineer District for use in deep, swift sections of the Mississippi River as well as in tributary rivers in that district. It consists primarily of a horizontal cylinder attached underneath a streamlined weight. Flap valves at the ends of the cylinder are held in the open position by catches and are released by a toggle arrangement either when the base of the sampler rests upon the river bed or by the impact of a small messenger

weight dropped down the suspending cable. Upon being released, the valves are actuated by small hinge springs and close down instantaneously on the ends of the cylinder.

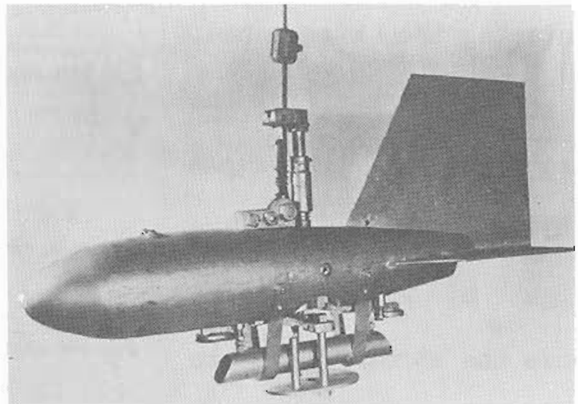


Fig. 39--Vicksburg District, U.S.E.D., horizontal toggle sampler.

Extensions are provided for the base plate beneath the sampler so that samples may be obtained at any desired point within about 5 ft. from the stream bed. Provision is made whereby a current meter may be suspended at the front end of the streamlined weight and velocity readings obtained at the same time that the sediment samples are taken. The weights are interchangeable so that a size which best adapts the sampler to the particular stream conditions may be used.

67. <u>Vicksburg District, U.S.E.D., electrically operated horizontal sampler</u>--The sampler, shown in Fig. 40, was developed by the Vicksburg U. S. Engineer District and is essentially the same as the toggle trap described in Section 66. The flap valves are held open by a catch mechanism which is released by a small solonoid plunger when energized by an electric current. When released, the valves are closed by the tension of a wire spring. The entire electrical mechanism is enclosed within the streamlined weight and the sample cylinder is suspended immediately below.

For depths about 2 ft. or more above the river bed, the desired depth of sampling is set by an indicator on the sounding reel and the current to actuate the solonoid plunger is supplied when this depth is reached. For sampling near the bottom a pipe of the necessary length

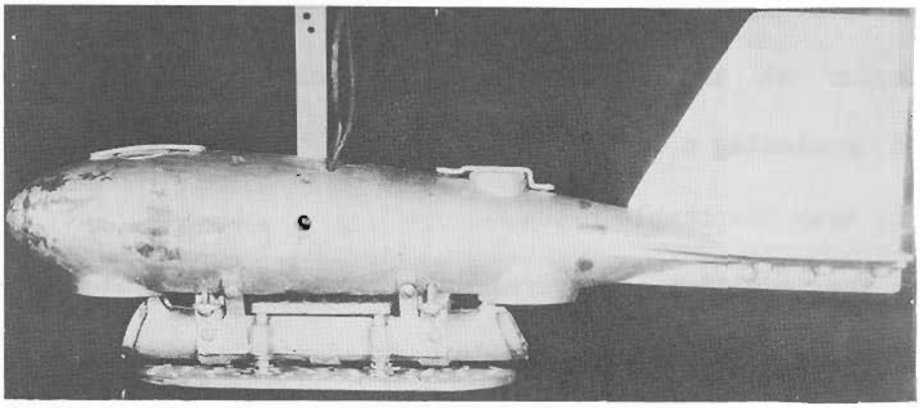


Fig. 40--Vicksburg District, U.S.E.D., electrically operated horizontal sampler.

with a flange on the lower end is attached to the bottom plate of the sampler. Contact of the flange with the stream bed mechanically closes the switch mounted just beneath the streamlined weight and electric current is supplied to the solonoid.

68. Electric horizontal trap sampler of the U. S. Waterways Experiment Station--An electrically operated sampler has been designed recently at the U. S. Waterways Experiment Station, Vicksburg, Mississippi, by Mr. Spencer J. Buchanan. The sampler consists essentially of a brass tube suspended horizontally beneath a streamlined weight. This tube has an inside diameter of 1 in. and length such that the intake end extends beyond any disturbance created by the streamlined body. The water-sediment sample is trapped instantaneously when the plunger type valves, one near each end of the tube, are closed. The streamlined flat-bottom weight completely houses the operating mechanism of the sampler.

The plunger type valves are actuated by a strong spring and are held in the open position by catches which are released by a solonoid upon the application of an electric current. As the sampler is lowered to the desired depth, water is passing freely through the sample tube. To close the sampler at the desired sampling point, the electric current is supplied by closing a switch at the surface thereby releasing the plunger valves to trap the sample.

By the addition of several duplicate sample cylinders, each to be operated separately, the sampler is made adaptable for taking a series of samples over a period of time at the same depth to secure an average sample or to allow study of fluctuations in sediment concentrations.

69. Miscellaneous bottle type samplers--The sampler, shown in Fig. 41, which was described in Engineering News, May 18, 1893, is of historical interest being one of the earliest samplers of the simple bottle type. It consists of an ordinary small-neck bottle enclosed in a metal container and provided with a stopper which is removed at the desired depth by a pull on an auxiliary line.

Numerous other samplers of the same general type, sufficing for many of the less elaborate investigations, have been used extensively by various agencies.

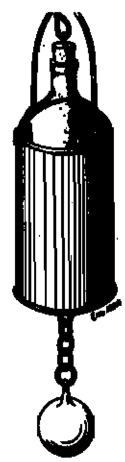


Fig. 41—Early bottle sampler.

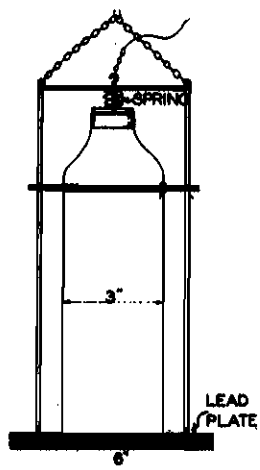


Fig. 42—Chinese copper bottle sampler.

A copper bottle, shown in Fig. 42, constitutes the sampler used in the Yellow River in China. The stopper is removed from the bottle by pulling an auxiliary line and is forced back to close the bottle by a coiled spring when tension on the auxiliary line is released. The metal bottle is used to avoid breakage by heavy suspended material.

Fig. 43--Port of Bordeaux Authority sampler.

The Port of Bordeaux Authority, France, devised the sampler shown in Fig. 43. The sample container, of approximately 9-qt. capacity, has a small intake opening at the top which is closed with a stopper. By pulling an auxiliary line this stopper is raised against the action of a spring to allow filling. Various size springs can be inserted to control the height to which the stopper is raised thereby regulating the rate of filling the sampler. The average time of filling is about 5 min.

Agencies of Sind Province, India, have used the sampler shown in Fig. 44. A small mouth copper bottle is held in a special brass frame and is opened and closed at the desired sampling point by an auxiliary line which raises the stopper against the force of a coiled spring. The spring forces the stopper back in the bottle when the auxiliary line is released.

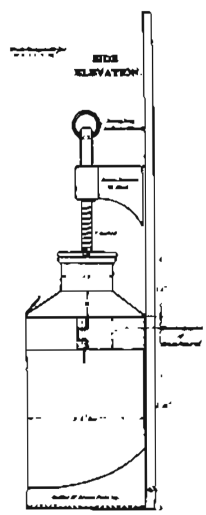


Fig. 44--Copper bottle sampler used in India.

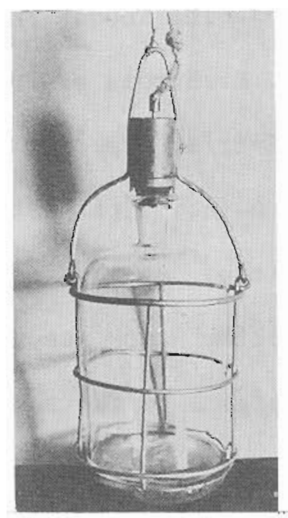
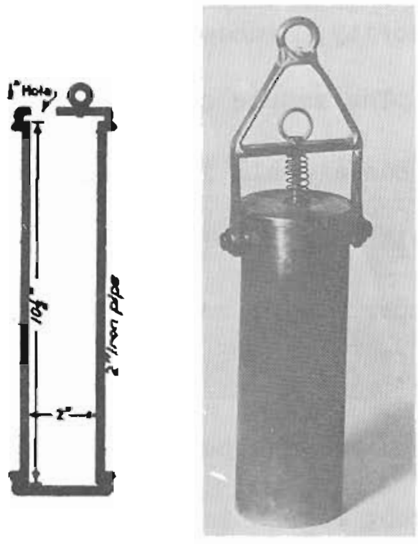


Fig. 45--Hjulstrom bottle sampler.

The sampler, shown in Fig. 45, used by Filip Hjulstrom (22) in his observations on the River Fyris, Sweden, consists of a small-neck glass bottle enclosed in a wire cage. The stopper is removed from the bottle at the desired sampling depth by



Early type. Later type.

Fig. 46--Yuma sampler, U. S. Bureau of Reclamation.

70. <u>Yuma and Topock samplers</u>--The Yuma sampler, shown in Fig. 46, devised by the U. S. Bureau of Reclamation for investigations in the Colorado River at Yuma, Arizona, consists of a section of 2-in. iron pipe, 10.5 in. long, closed at the bottom and fitted with a cap at the top having a hole of only 1/2-in. diameter. The intake hole is always open so as to collect a water-sediment sample while the sampler is lowered to the bottom and raised again to the surface. The later type Yuma sampler, now being used, is provided with a cap that can be lifted from the cylinder to facilitate emptying the sample into another container.

The Topock sampler, shown in Fig. 47, was used by the U. S. Bureau of Public Roads for sampling in the Colorado River at Topock, Arizona, and consisted of a section of 2.5-in. pipe 6.44 in. long, closed at the lower end and fitted at the top with a cap having a 5/8-in. hole. The bottom cap was provided with a connection for attaching weights to the sampler.

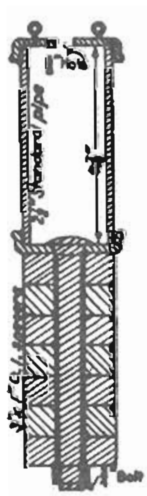
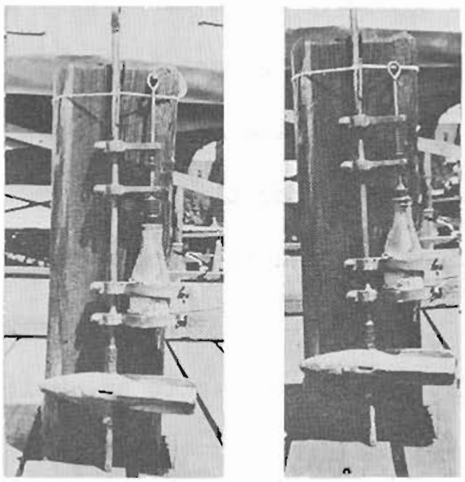


Fig.47--Topock sampler, U. S. Bureau of Public Roads.

71. <u>South Atlantic Division, U.S.E.D., bottle sampler</u>--This sampler, illustrated by Fig. 48, has been used by the South Atlantic U. S. Engineer Division for investigations in the Savannah River and in Savannah Harbor. It consists of a regular 1-qt. milk bottle mounted vertically alongside of a heavy iron rod which



Open Closed

Fig. 48--South Atlantic Division, U.S.E.D., bottle sampler.

serves as a frame for the sampler. The mechanism for opening and closing the bottle is attached to the frame directly above the bottle. The stopper is held down upon the mouth of the bottle by the pressure of a coil spring, and is pulled open and held open for sampling by an auxiliary suspension line. Releasing the pull on the line closes the sampler. A regular current meter weight is attached to the lower end of the iron bar to facilitate the use of the sampler in the river or in tidal currents.

72. Punjab bottle sampler--The sampler, shown in Fig. 49, was developed by engineers of the Punjab Irrigation Service of India for sampling in shallow streams. It consists of a small-neck bottle held in a frame which is attached coaxially to the end of a length of pipe. The bottle is opened and closed manually by means of a hand lever at the top and a rod inside the pipe connected to the bottle stopper.

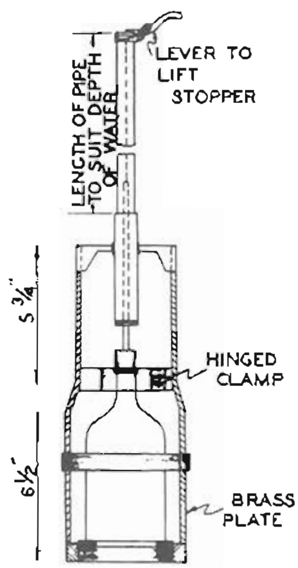


Fig. 49--Punjab bottle sampler.

73. Philadelphia District, U.S.E.D., sampler--The sampler, shown in Fig. 50, was developed in the Philadelphia District of the U. S. Engineer Department for use as a suspended sediment sampler but because of the weight and difficulty of handling, it was used primarily for sampling close to the stream bed. The sample

Fig. 50--Philadelphia District, U.S.E.D., sampler.

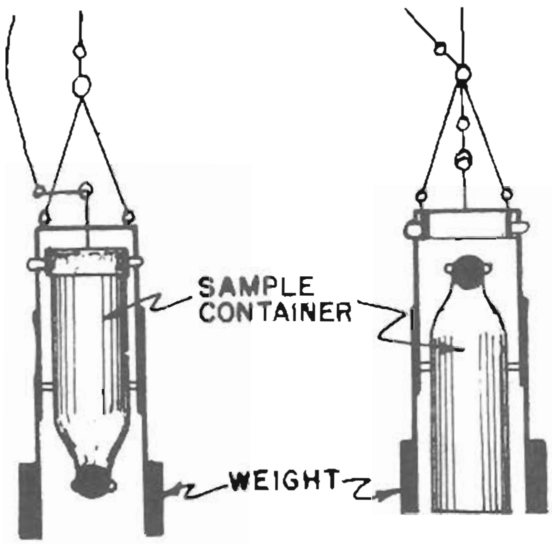
container is a large glass cylinder which is covered at each end with a heavy metal plate. There are two 1/4-in. holes in the bottom cover for the entrance of the water and a small hole in the top plate for the air exhaust, all of which are opened and closed by a large piston rod within the cylinder.

By shifting the weight of the sampler to an auxiliary suspension line connected directly to the piston shaft in the sample container, the piston is raised and the openings are uncovered allowing the water sample to run in at the bottom and the air to exhaust at the top. Release of the tension on the auxiliary line, after sufficient time has been allowed for collecting the sample, allows the piston to close the openings again.

The sample container is mounted from four vertical posts of the frame so that the height of water entrance above the stream bed is adjustable within the limits of 1 to 12 in. The vertical parts are attached to a large, flat, circular rim weighted with lead, which serves as the base of the sampler when resting flat upon the stream bed.

An unsatisfactory feature of this sampler is that when used in streams of soft bottoms it settles down into the bed.

74. Hochstetter bottle sampler--The sampler, shown in Fig. 51, which has been used in Bavaria, consists of a bottle mounted in a frame so that it can be rotated about a horizontal axis. The sampler is lowered to the sampling point with the bottle inverted. A pull on an auxiliary line released the bottle and allows it to tip to the upright position and collect the sample. A rubber ball within the bottle floats and seals

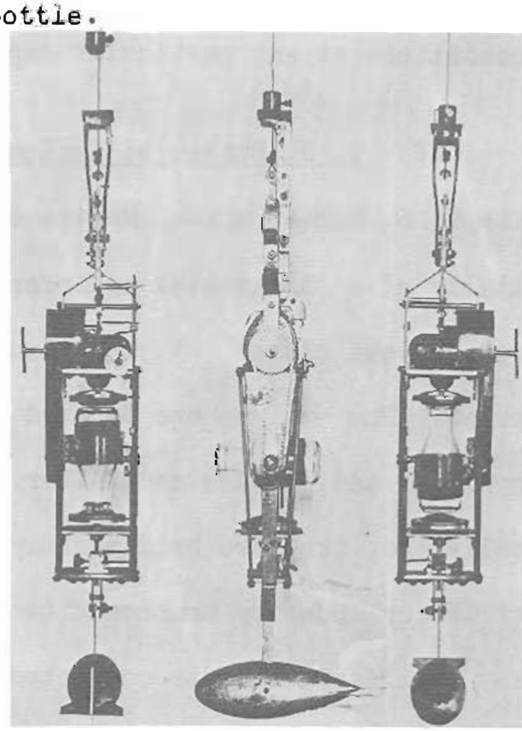


Bottle inverted, air prevents filling. Bottle upright, filled & closed with fall float.

Fig. 51--Hochstetter bottle sampler.

the mouth of the bottle when it is full. The inverted position of the bottle prevents the escape of air as the sampler is lowered and the rubber ball tends to decrease premature filling. However, in lowering the sampler to great depths, premature filling does take place due to the increased hydrostatic head and a consequent decrease in the volume of air within the bottle.

75. <u>Mundt bottle sampler</u>--The sampler, shown in Fig. 52, was designed by Mr. H. W. Mundt (37) for use by the Missouri State Bureau of Geology and Mines and was illustrated and described in the 1927-28 biennial report of that bureau. The sample is collected in an ordinary pint milk bottle operated by an automatic mechanism. The sample bottle is placed in the sampler in the inverted position, its mouth sealed by a lower seat valve. When a messenger weight, dropped down the suspension line, starts the mechanism the bottle



(a) (b) (c)

Fig. 52--Mundt bottle sampler.

(a) Bottle inverted and closed.
(b) Open bottle revolving to the vertical position and facing into stream.
(c) Bottle upright and closed.

is rotated slowly toward the current on a horizontal axis to the upright position. At the beginning of rotation the mouth slides off of the lower valve and the bottle is opened. It fills as it rotates and as it approaches the vertical position the mouth of the bottle slides under the upper valve sealing the opening.

A spring motor from a standard door check with a sprocket and chain drive furnishes the power to rotate the sample bottle. To compensate for variations in the rate of filling due to a decrease of air volume in the sampler under increased hydrostatic pressures, and to regulate the volume of sample collected at any depth, the rate of rotation of the bottle is controlled by a timing device and is adjustable for specific conditions at any particular depth.

76. <u>U. S. Bureau of Reclamation slow filling horizontal sampler</u>-- The U. S. Bureau of Reclamation sampler, shown in Fig. 53, consists essentially of a horizontal cylinder provided with disk type valves which are opened and closed at the desired sampling point. The valves are mounted axially on the cylinder and, before and after the sample is collected, they are held tightly over the ends of the cylinder by tension of two door springs. An auxiliary line is connected to the valves by individual lever arms. By pulling on the line the valves are pulled short distances away from the cylinder providing a somewhat restricted passage for flow through the sampler. Releasing the tension on the auxiliary

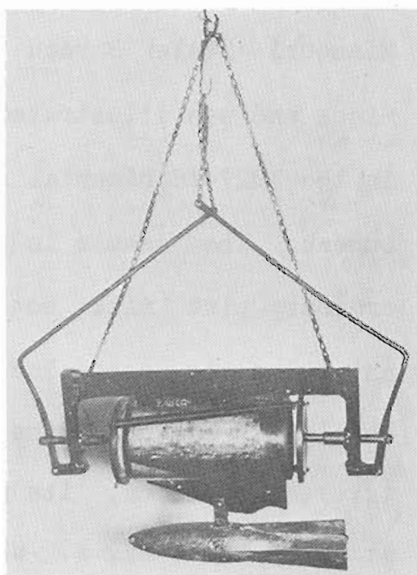


Fig. 53--U. S. Bureau of Reclamation slow filling sampler.

line closes the valves. A streamlined weight suspended beneath the sampler facilitates sampling in swift streams.

77. St. Paul District, U.S.E.D., bottle sampler--The St. Paul U. S. Engineer District bottle sampler, shown in Fig. 54, consists of an ordinary pint milk bottle suspended in front of a current meter weight suspended from a cable. A lever raises the cap from the bottle at the desired depth for sampling when a messenger weight, dropped down the suspension cable, strikes the opposite end of the lever. A cork float inside the bottle rises with the sample and closes the bottle when it is full.

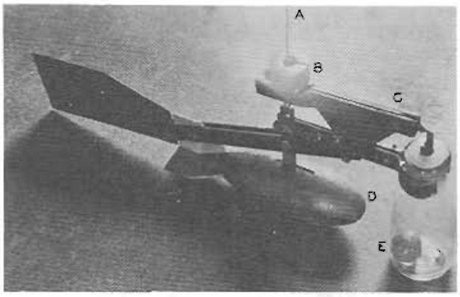


Fig. 54--St. Paul District, U.S.E.D., bottle sampler.

78. U. S. Geological Survey bottle sampler--The suspended sediment sampler, shown in Fig. 55, used extensively by the U. S. Geological Survey, consists essentially of an ordinary pint milk bottle enclosed in a tubular brass holder. The mouth of the bottle is throttled with a rubber insert through which there is a small hole. Inserts with various sized holes are used to regulate the rate at which the sampler fills. No provision is made for opening or closing the bottle. In operation the sampler is lowered and raised throughout the depth of the stream at such a rate as to be not quite full when it returns to the surface. It may also be lowered quickly to a particular sampling point and allowed to collect the sample at the point before raising


Fig. 55--U.S.G.S. bottle sampler.

to the surface. Heavy lead weights may be attached to the bottom of the bottle holder when needed.

79. U. S. Department of Agriculture bottle sampler--The sampler shown in Fig. 56 was used by the U. S. Department of Agriculture in studies of the suspended sediment concentrations of streams in Texas and is being used also by the U. S. Engineers in the Southwestern Division. The sampler consists essentially of a small-neck bottle attached to an ordinary current meter suspension bar and lead weight. Prior to sampling the bottle is closed by a stopper which is removed at the desired sampling depth by pulling an auxiliary line. No provision is made to close the bottle after the sample is collected. A door spring prevents removal of the bottle stopper by the current drag against the auxiliary line.

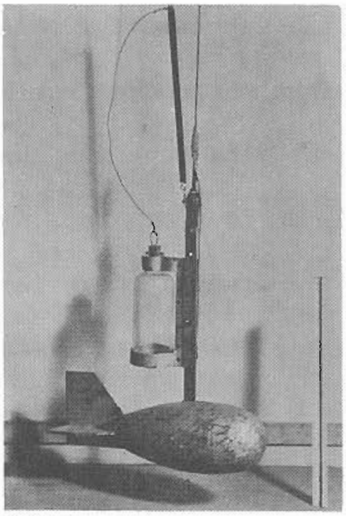
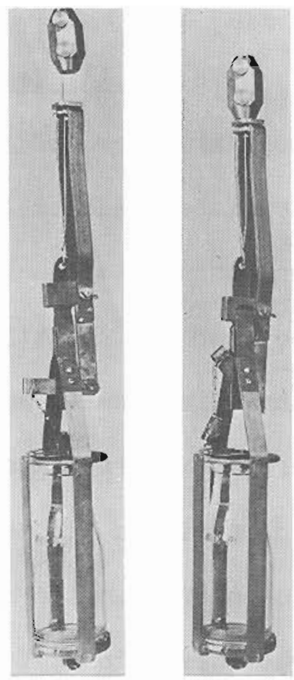


Fig. 56--U.S.D.A. bottle sampler.

80. U. S. Geological Survey Colorado sampler--The Colorado sampler, shown in Fig. 57, used by the U. S. Geological Survey in extensive investigations in the Colorado River, consists essentially of a pint milk bottle suspended in a simple frame. The bottle is capped by a rubber insert having a hole of such diameter as to obtain the desired rate of filling. Prior to sampling the hole is closed with a rubber stopper. At the desired sampling point the stopper is removed by



Closed Open

Fig. 57--Colorado sampler.

a simple lever system which is actuated by the impact of a messenger weight dropped down the suspending cable. No provision is made for closing the bottle after the sample is collected. When necessary, a current-meter weight may be suspended from the bottom of the sampler.

In an earlier design of the Colorado sampler, the bottle mouth was capped with a regular milk bottle cap. In the cap there was a 5/8-in. hole which, prior to sampling, was covered with heavy paper cemented to the cap. The sampler was opened to receive the sample by puncturing the paper cover with a knife blade. The knife blade mechanism was actuated by the impact of a messenger weight in much the same manner as the stopper mechanism in the present design.

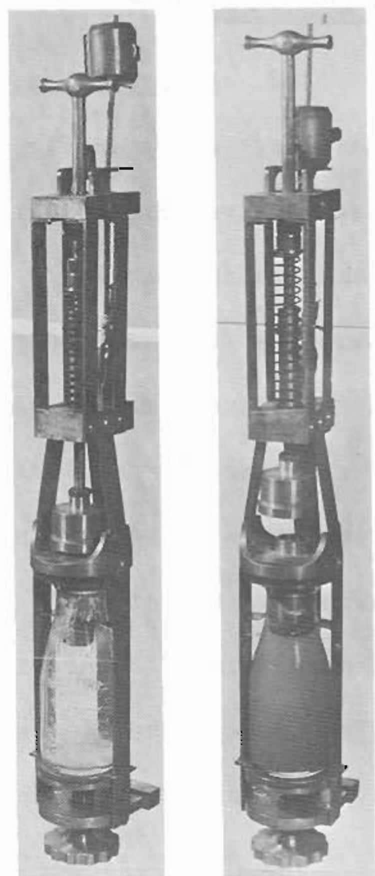


Fig. 58--Straub sampler.

81. Straub sampler--The sampler used in the Missouri River Division, U. S. Engineer Department, shown in Fig. 58, utilizes a pint milk bottle for the sample container. The bottle is clamped securely in the sampler frame between two rubber faced grips, the lower one adjustable by means of a heavy screw. Prior to sampling, the bottle is closed by a valve which is seated over a 1-in. opening in the upper bottle grip. A trigger mechanism holds the valve in the closed position against the tension of a coil spring. A messenger weight dropped down the suspension line trips the trigger and the valve is raised to the open position. The water sample flows through

the 1-in. opening and, when full, the sampler is closed by a cork float within the bottle.

When sampling in high velocities, streamlined weights are added below the sampler to decrease the inclination from the vertical or the downstream drift.

In an earlier design of this sampler, the bottle was covered with a heavy paper cap. At the desired sampling point, a knife blade, actuated by the messenger weight, punctured the bottle cap and allowed the sampler to fill.

82. Anderson-Einstein time-integrating sampler--The Anderson-Einstein sampler, shown in Fig. 59, is a time-integrating type developed at the Enoree River Experiment Station, Greenville, South Carolina, by the Soil Conservation Service. It consists of a pint milk bottle equipped with a two-hole rubber stopper through which two 1/4-in. tubes extend, one for water intake and the other for air exhaust. The water intake tube faces directly into the current to minimize any directional change of the water-sediment in flowing into the container. The air exhaust tube is bent downstream to effect smooth evacuation of the air.

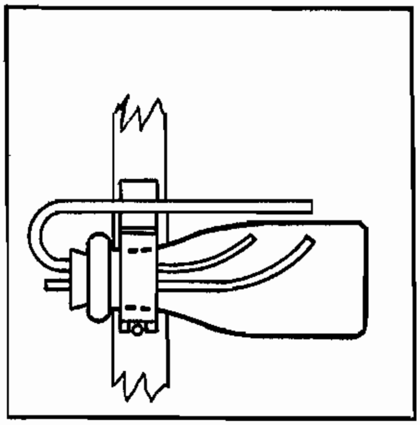
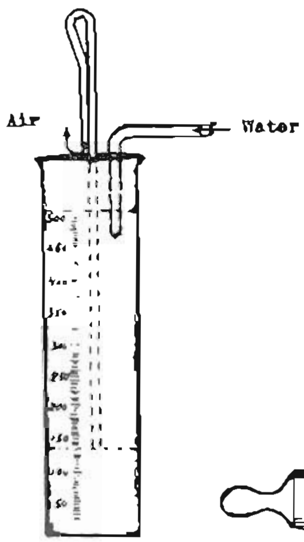


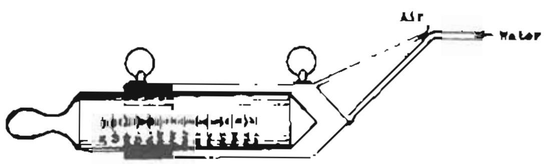
Fig. 59--Anderson-Einstein sampler.

One or more samplers may be clamped to a rigid upright that may either extend from the surface to the stream bed or be suspended by a cable. The sampler is adapted primarily to sampling shallow streams and, if calibrated, may be used to measure the stream velocity at the sampling point. A similar sampler was developed by Mr. S. K. Love of the Geological Survey.

83. Graduated time-integrating samplers--In principle the samplers, shown in Fig. 60, a and b, described by Jakuschoff (29), are very similar to the Anderson-Einstein sampler. Each consists of a graduated container with intake tubes for the water and siphon tubes to exhaust the air. The volume of sample collected in the Gluschkoff sampler which has been used in Russia is controlled by raising or lowering the air exhaust tube. Filling stops shortly after the water covers the mouth of the air exhaust tube. The volume of sample collected in the Jakuschoff sampler is controlled by a piston inserted into the container which adjusts the capacity of the container to equal the volume of sample desired.



a. Gluschkoff



b. Jakuschoff

Fig. 60--Graduated time-integrating samplers.

84. Dutch Federal Authority sampler--A description of the sampler, shown in Fig. 61, recently developed and used by the Dutch Federal Authority, has been received from Professor J. T. Thijsse of Delft, Holland. This sampler operates as a sedimentation chamber, the water-sediment flowing through a relatively small intake into a large chamber with a resulting decrease in

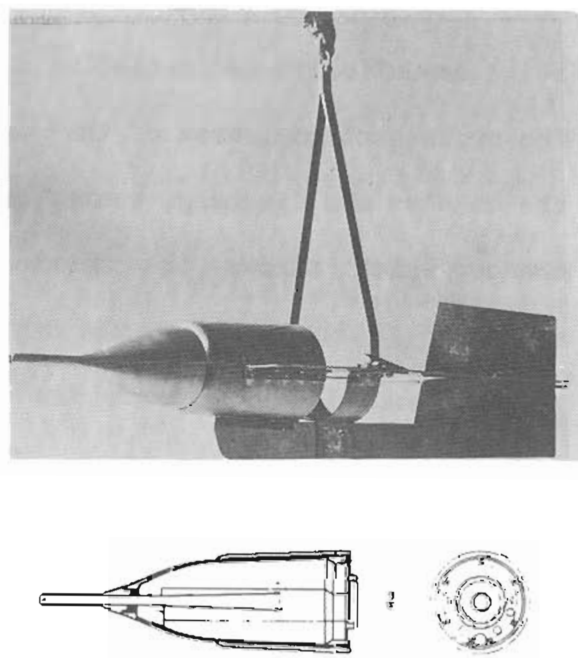


Fig. 61--Dutch Federal Authority sampler.

velocity. The flow is directed by baffles toward the rear of the chamber, back to the front and then to the exit at the rear. The relatively long detention period and decreased velocity allows the heavier suspended sediment to settle in the chamber. To determine the sediment concentration it is necessary to know the duration of sampling and the stream velocity at the sampling point as well as the quantity of material collected. It is also necessary that the sampler be calibrated to determine the degree of error due to fine particles not depositing in the sampler.

85. <u>Canter Cremer sampler</u>--The sampler, shown in Fig. 62, was developed by Mr. Canter Cremer and has been used in Holland since about 1918.

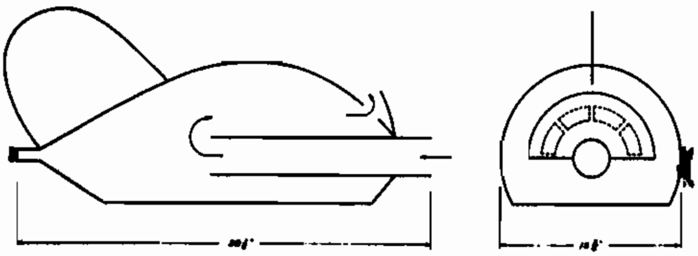


Fig. 62--Canter Cremer sampler.

It is essentially a sedimentation chamber through which the water flows. The cross-sectional area of the intake is small in comparison to that of the chamber and discharge vents, causing a relatively low velocity in the chamber which allows the heavier sediment to settle out. The water-sediment is directed from the entrance to the rear of the chamber, reverses, and flows through the chamber at a reduced velocity toward discharge ports near the front. These ports are located in such a manner that the stream flow past the sampler creates suction to draw the water through the chamber.

The percentage of suspended material that will be deposited in the chamber depends upon the size of particles and the period of detention within the chamber. The sampler has been calibrated to correct the measured sediment for various particle sizes and stream velocities. The calibration showed that with material of .5 to 1.0 mm. size and stream velocities of 4 to 5 ft./sec., up to about 18 per cent of the total quantity of material passed through the chamber. With finer materials the loss increased rapidly and for fine sands of less than .3 mm. particle diameter, as much as 70 per cent of the suspended load, by volume, passed through the sampler. The sampler is adapted primarily to sampling where coarse materials predominate.

86. Collapsible container samplers--A sampler with a container which is collapsed prior to filling has a desirable characteristic in that it tends to fill in proportion to the stream velocity. Being devoid of air, the sampler is unaffected in its filling by the hydrostatic pressures of depth of sampling.

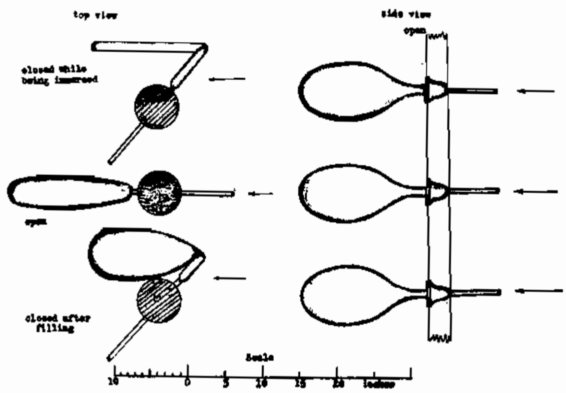


Fig. 63—Gluschkoff time-integrating collapsible bag sampler.

The Gluschkoff sampler, Fig. 63, has been used in Russia. It features several collapsible rubber bags, unprotected, attached to a handle, enabling the collection of a series of simultaneous samples from several depths. Prior to and after filling the handle is turned so as to face the intake downstream thereby pinching the rubber neck to close the bags.

The collapsible bag type sampler used in Germany, Fig. 64, consists of an India rubber balloon enclosed in a tin box. A brass intake tube extends out in front of the box facing into the stream. The mouth of the

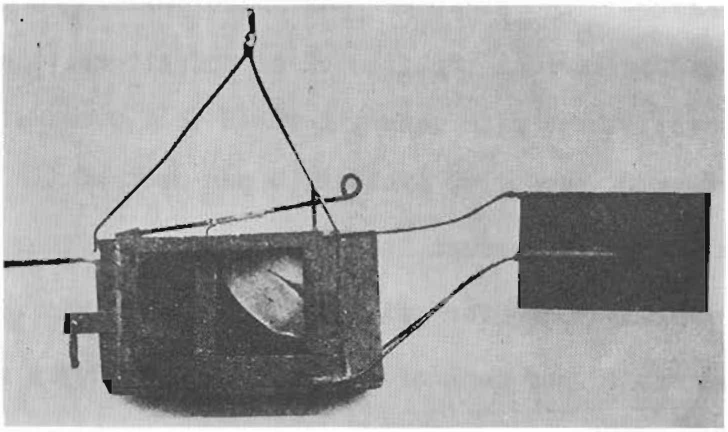


Fig. 64--Rhine Works Authority collapsible bag sampler.

balloon is opened and closed by a lever operated pinch clamp mechanism which is controlled by an auxiliary line.

87. Lake States Forest Experiment Station time-integrating sampler--The Lake States Forest Experiment Station sampler, shown in Fig. 65, commonly referred to as the "swordfish" sampler, consists of a horizontal sample container with intake tube for filling and a vent for the escape of air. The intake of 1/4-in. brass tubing projects upstream from the

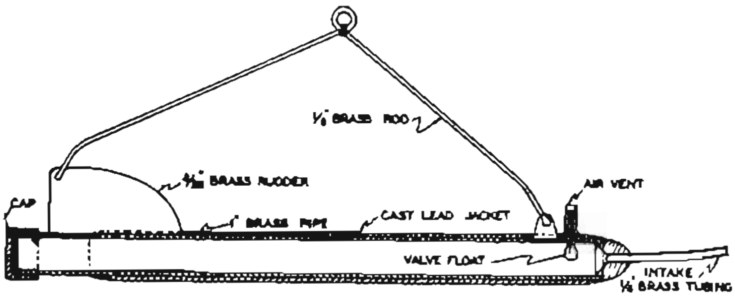


Fig. 65--Lake States Forest Experiment Station time-integrating sampler.

end of the sample container. The air exhaust tube projects vertically at the upstream end of the sample container and is provided with a small float valve which closes the exhaust when the sampler is filled to prevent further infiltration of water-sediment. The capacity of the sampler is approximately 1/2 pt. or 230 cc.

The sampler has been used primarily in the depth-integrating method of sampling, lowering to the stream bed and raising to the surface at such a rate that the container is not quite filled upon reaching the surface.

88. Rock Island District, U.S.E.D., simplified time-integrating sampler--The Rock Island U. S. Engineer District of the War Department has developed from the preceding sampler the simplified slow-filling sampler, shown in Fig. 66, for use in extensive sediment investigations of that district. The sampler consists essentially of a horizontal sample container with intake tube and controlled air exhaust vent. The intake is a 1/4-in. brass tube, flush at the upstream end of the streamlined sample container, and faces directly into the stream flow. The air exhaust tube extends upward and is inclined downstream to provide suction for the evacuation of the air from the sampler. The exhaust tube is provided with a brass stop cock which is adjustable to predetermined positions to regulate the rate of air escape and consequently controls the rate of filling.

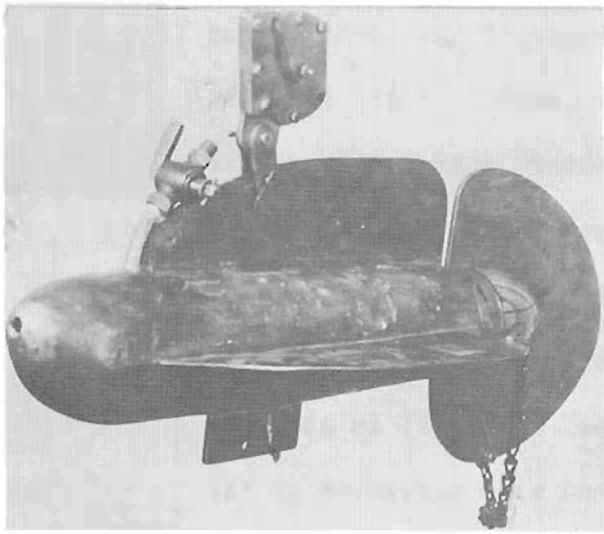
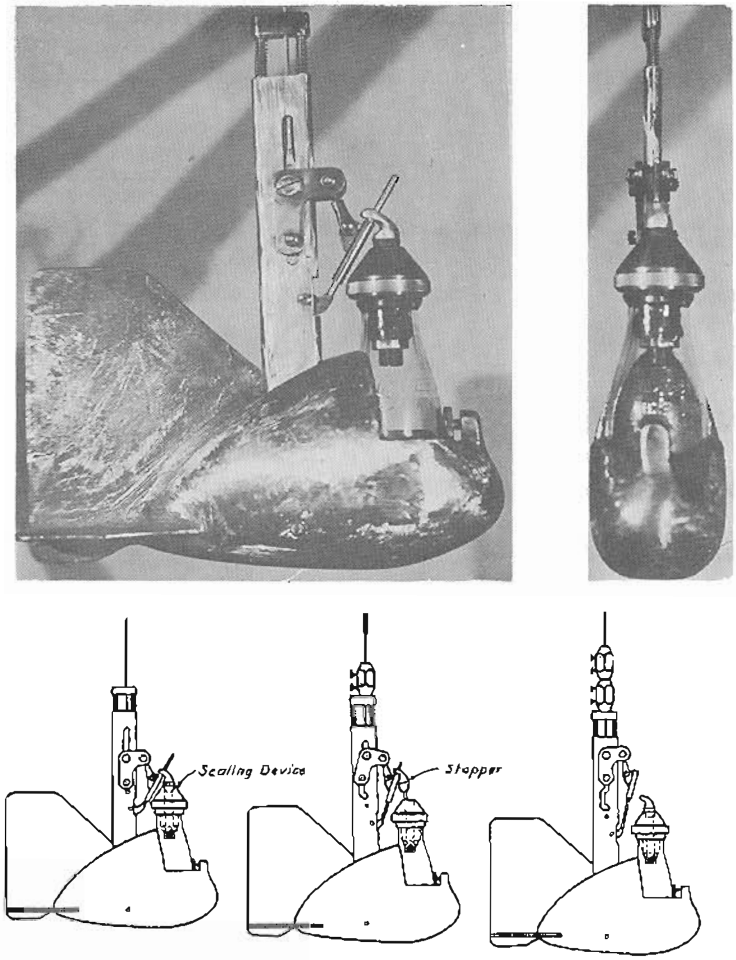


Fig. 66--Rock Island District, U.S.E.D., simplified time-integrating sampler.

The sampler is used principally for the depth-integration method of sampling, being lowered and raised throughout the stream depth at a uniform rate. Its capacity is approximately 1-1/3 pt. or about 600 cc.

89. <u>Frazier, U.S.G.S., time-integrating sampler</u>--The time-integrating sampler, shown in Fig. 67, was developed by Mr. A. H Frazier of the U. S. Geological Survey and has been used to some extent in that department. The sample container is a regular pint milk bottle clamped into a recess in a streamlined bronze weight. A sealing device inserted into the mouth of the bottle has a small hole for the water entrance and air exhaust which is closed by a rubber stopper. A tube guides the stopper to which it is attached and also serves as an air exhaust, the air escaping through small vents in the back side of the tube. A small coil spring connecting the bottom of this tube to the main body of the sealing device returns the stopper to the seat in the hole when released.



(a) - This sampler ready to be submerged The stopper is seated in intake tube

(b) - The first weight has been dropped, raising stopper from intake tube allowing the bottle to fill

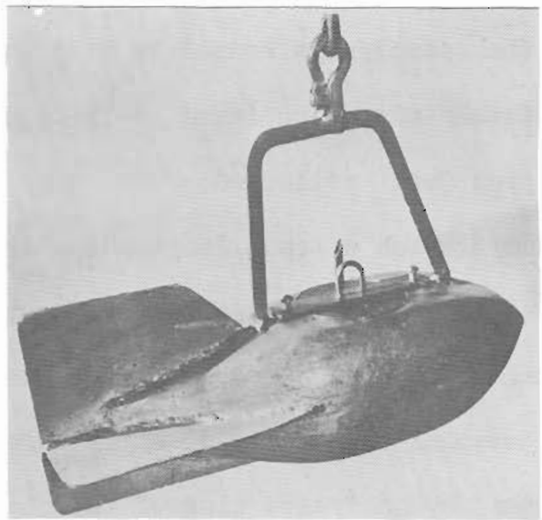
(c) - The second weight has been dropped The stopper has been released from the trip mechanism and has been pulled back into the bottle by the spring.

Fig. 67--Frazier, U.S.G.S., time-integrating sampler.

The double trip mechanism for opening and closing the bottle is built into a flat stainless steel tube which also acts as the connection between the bronze weight and the suspension cable. A small messenger weight dropped down the suspension cable depresses a plunger and allows the heavy bronze weight to drop 1 in. By this action, the stopper is raised from the sealing device and the water flows into the sampler through the entrance. At the impact of a second messenger weight another trip action releases the stopper which is pulled back into the sealing device by the spring and closes the sampler. The entire sampler measures only 16 in. in height, is streamlined, and capable of sampling down to a foot from the stream bed. The trip mechanism, utilizing the bronze weight for the motivating force, is very positive in action.

90. <u>Omaha District, U.S.E.D., time-integrating sampler</u>--The time-integrating sampler, shown in Fig. 68, was designed by the Omaha U. S.

Unassembled, showing sample in bottle ready for shipment to laboratory.



Assembled, ready for sampling.

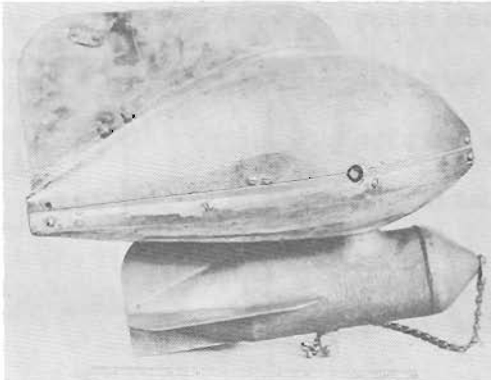
Fig. 68--Omaha District, U.S.E.D., time-integrating sampler.

Engineer District of the War Department and has been used in extensive sediment investigations of that district. The sample container, a pint wide-mouth fruit jar, fits into a recess in a streamlined weight. The cap for the container is made of brass and has a 1/4-in. orifice for the water intake and a siphon of 3/16-in. copper tubing for the air exhaust. A large cork float, attached to the cap, closes both the intake orifice and the air exhaust tube when the bottle is full, but no provision is made for keeping the sampler closed until the desired sampling depth is reached. After the sample is collected, the container is removed, the cap is replaced with a regular jar lid, and the sample is ready to be shipped to the laboratory. Streamlined weights of various sizes are available for use in different stream conditions.

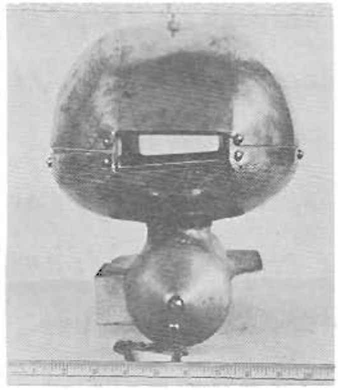
91. Rock Island District, U.S.E.D., time-integrating sampler--The time-integrating sampler, shown in Fig. 69, was developed by the Rock Island District of the U.S. Engineer Department. The operating mechanism of the sampler is housed in a streamlined body with a streamlined sample container suspended immediately below. A series of small instantaneous samples are collected from the relatively undisturbed flow within a conduit which extends longitudinally through the streamlined body.

The conduit, about 18 in. long, has a trapezoidal cross section with an area of about 3 sq. in. The water of the stream enters at the nose of the sampler and passes directly through it. A section of the conduit is formed by a valve plug of the stop cock type and has an opening of the same cross section as the rest of the conduit. When the valve is turned at 90 degrees to the open position, a sample trapped within its section is spilled into the container below. The conduit is closed to flow until the valve is returned again to the open position. A series of these samples constitutes a composite time-integrated sample.

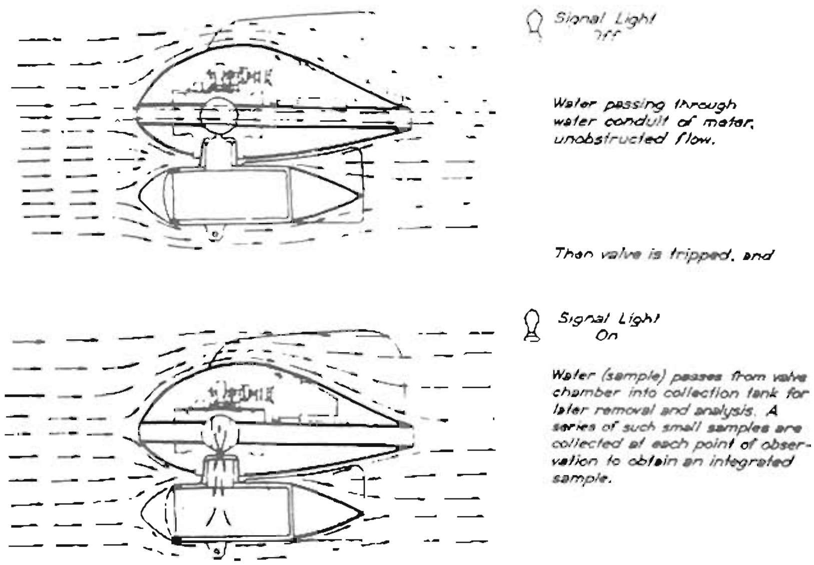
The valve is actuated almost instantaneously by a heavy clock spring, and controlled by a ratchet and trigger mechanism which stops the valve



Side view.



Front view, open.



Schematic diagram.

Fig. 69--Rock Island District, U.S.E.D., time-integrating sampler.

at each quarter turn. The ratchet is released and the valve allowed to rotate instantaneously through 90 degrees when an electric circuit which actuates the trigger mechanism is closed by the operator. A signal light at the surface is turned on while the valve is in the closed position.

92. U. S. Bureau of Reclamation pumping sampler--The sampler, shown in Fig. 70, was developed by the U. S. Bureau of Reclamation and used for investigations in the lower Colorado River. The water-sediment sample is

sucked in through a pipe or hose whose entrance, placed at the desired sampling point, faces into the current. The suction is produced with a pump which evacuates the water or air from a 50-gal. tank connected directly to the sampling hose. The water from the sampling point flows continuously through the hose into the tank until the flow is diverted into a sample bottle by turning valves which connect both the sampling hose and the vacuum to the bottle.

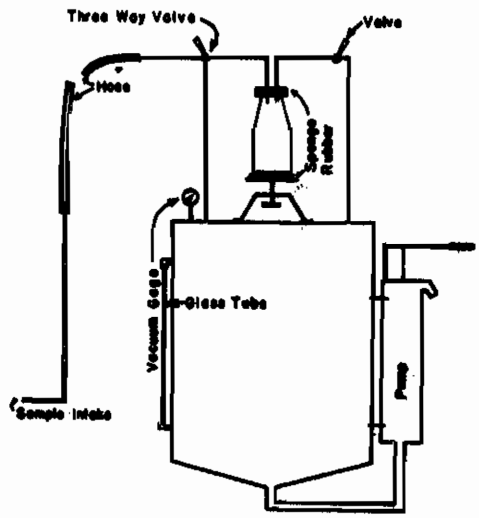


Fig. 70--U. S. Bureau of Reclamation pumping sampler.

93. <u>Baltimore Bureau of Water Supply vacuum sampler</u>--The vacuum sampler, shown in Fig. 71, described by Mr. Edward S. Hopkins in Engineering News-Record, May 31, 1928, has been used in the Bureau of Water Supply, Baltimore, Maryland. The sampler consists of the "depth sampler" which is an inverted funnel, 7 in. in diameter at the mouth, and 6 in. high; a glass jar "collecting bottle"; and a pump with the necessary connections for evacuating the collecting bottle. Vacuum, produced by a hand pump and laboratory vacuum flask at the surface, is applied to the collecting bottle through a rubber hose and the water is sucked through the depth sampler up into the collecting bottle.

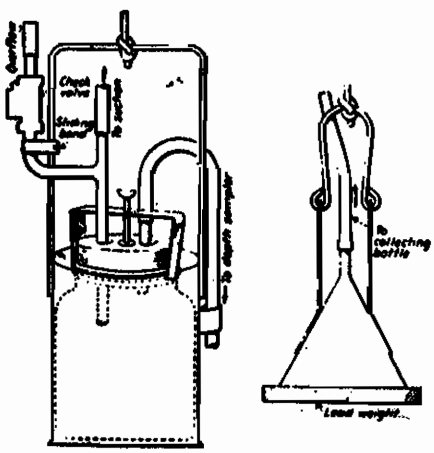


Fig. 71--Baltimore Bureau of Water Supply vacuum sampler.

The water is pumped through the collecting bottle until the flow is established and the final sample can be trapped at any desired time. When sampling from a high bridge it is necessary to suspend the collecting bottle a distance above the water surface not to exceed the maximum vacuum which can be obtained with the pump.

94. Italian pump and centrifuge sampler--A boat, equipped as shown in Fig. 72, has been used for experimental sediment investigations in the Po River in Italy. The installation consists essentially of a hand pump with an intake hose reaching to the sampling point and a centrifuge for segregating the suspended load from the water. A reel is provided for the intake hose to regulate the depth of sampling, and a water meter registers the quantity of water pumped. The suspended load, separated by the centrifuge is dried and weighed to determine the concentration in the total volume of water-sediment pumped.

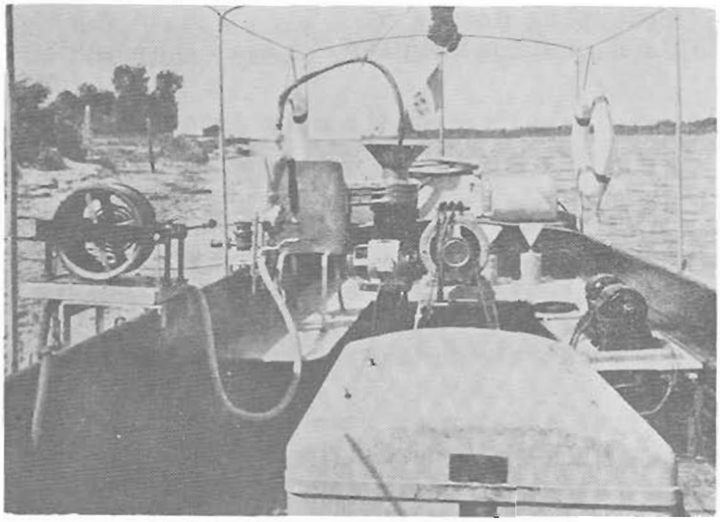


Fig. 72--Italian pump and centrifuge sampler.

95. Holland pumping sampler--A pumping sampler used by the Study Department of the Directorate of Upperrivers at Arnhem, Holland, consists of a boat equipped with a suction pump system and collecting tank for the sample of water-sediment. The collecting tank features a glass measuring tube at the bottom into which the sediment settles. The rate of sample intake is measured as the sample discharges into the collecting tank and

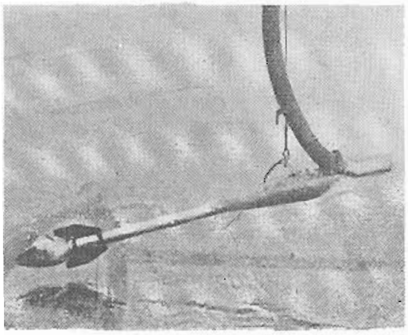


Fig. 73--Intake orienting device of Holland pumping sampler.

is regulated so as to equal the quantity of water passing an area equivalent to the cross-sectional area of the intake.

A feature of the sampling system is the orienting device, shown in Fig. 73, which is attached rigidly to the metallic mouthpiece of the intake hose. It is a streamlined weighted body equipped with fins which keeps the mouth of the hose facing directly into the current.

96. <u>Sind siphon sampler</u>--A siphon sampler developed by the Province of Sind, India, has the unique feature of being able to control the velocity at the intake. The apparatus consists of a 5/8-in. pipe siphon with its end tapped into the side of a 1.5-in. pipe, 2 ft. long, which faces into the stream and allows the water to flow freely through it. The sample, siphoned from the stream flow, discharges into a cylindrical tank submerged to a depth of about 6 ft. below the water surface. The rate of flow through the siphon is controlled by adjusting the distance between the discharge end of the siphon and the surface of the stream.

97. <u>The photo-electric turbidity meter</u>--One of the more advanced designs of equipment for adapting the turbidity measuring principle of the photo-electric cell to the measurement of suspended sediment is illustrated in Fig. 74. It is described by Jakuschoff (29) who found in preliminary experiments, as did Hjulstrom (22), a decided tendency for unreliability. In operation the suspension flows through the long horizontal cylinder passing between the light source and the photo-electric

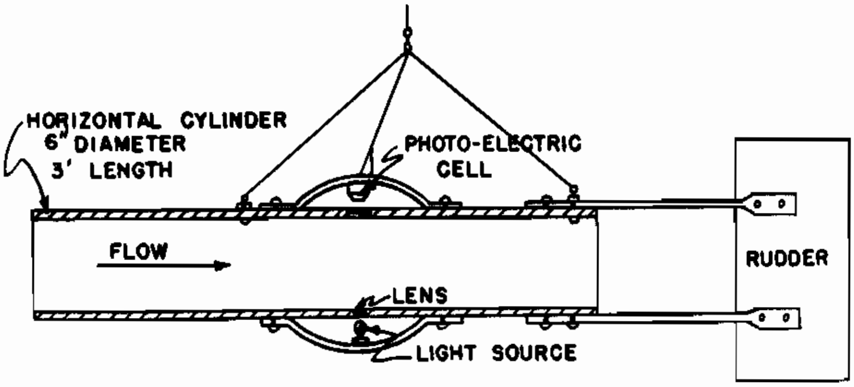


Fig. 74--Photo-electric turbidity meter.

cell which are enclosed in water-tight chambers on opposite sides of the cylinder. The intensity of the light reaching the cell, a function of the turbidity of the suspension, is indicated by the intensity of the electric current through the cell.

XI. SUMMARY AND CONCLUSIONS

98. Scope of report--This report is one phase of a joint project conducted by a number of government agencies to study the equipment, field technique, and laboratory procedures involved in sediment investigations. Specifically, this report includes the following subjects concerned with the sampling of suspended load:

a. A history and discussion of field practices in selection of sampling points across the stream.

b. A history and discussion of field practices in determining the depths at which samples are taken.

c. Frequency of sampling.

d. A history and discussion of sampling equipment including a classification by mode of action and a listing of the principal characteristics of groups.

99. Study of field technique--The history of the development of field practice summarizes fifty-six investigations extending from 1808 to the present time, including studies in the United States, France, Germany, Finland, Sweden, Italy, Central Asia, Turkestan, Iraq, Afghanistan, India, China, Egypt, South Africa, and Argentina.

The methods of selecting verticals to be sampled are considered in Chapter III. Most of the methods are arbitrary, including single vertical, 1/4, 1/2, and 3/4 width, and any other number of verticals selected with only minor consideration of velocity distribution. The 1/6, 1/2, and 5/6 width method has been verified experimentally for a few streams but is not necessarily applicable to other streams. The methods having rational justification are those in which the verticals are selected so as to represent equal discharges or where weights proportional to the discharge are applied to verticals more or less arbitrarily chosen. An approximation of the former method has been to select verticals estimated visually to be at midpoints of sections of equal discharge. A method of locating directly the verticals representing equal discharges, based on previous records of stage and velocity distribution, is presented.

Data concerning vertical distribution of suspended sediment for different investigations are presented in Table 3, Chapter IV, and the relation of vertical sediment distribution to methods of sampling in the vertical is discussed. For purposes of discussion, the methods of sampling a vertical are divided into three classes: arbitrary, empirical, and rational. The methods of sampling at surface, mid-depth or any other point or combination of points are arbitrary unless they consider velocity and sediment distributions or unless coefficients are obtained from more complete studies. Most common of the empirical methods are the 0.6 depth method and the surface method using coefficients based on previous experimentation. The surface, mid-depth and bottom method, with mid-depth concentration given double weight, is discussed with the empirical methods. The depth-integration method as performed at present, without regard to velocity distribution or hydrostatic pressure, is not a fully rational method. The precise, Straub, Luby, and depth-integration methods are considered rational if velocity distribution and hydrostatic pressure are properly accounted for. All these methods are discussed in Chapter IV.

The use of rational methods of selecting verticals and the location of points in these verticals will, in general, give the most accurate results.

The amount of error resulting from the various methods of selecting sampling points is as yet uncertain, but a study is being made of the accuracy of various methods of selecting points in the vertical.

Frequency of sampling is emphasized as one of the more important considerations in a sampling program, and unfortunately, it does not lend itself readily to solution by rational or analytical methods. Whether solved by rational methods or determined by somewhat arbitrary methods it is dependent upon the rate and magnitude of change in sediment concentration, which in turn, depends to a considerable extent upon characteristics of each stream and storm. At present the most practical criterion of where and how frequently to sample the suspended load, other than periodic routine measurements, is change in stage. In general, more frequent sampling is necessary preceding a peak than following a peak. The amount of increase in frequency indirectly depends to a considerable extent upon size of drainage area, with small flashy streams generally requiring very frequent sampling during rising stages.

A direct relationship between water and sediment discharge cannot be relied upon to provide even a fair estimate of total suspended load at any short period, but this relation is often used for total loads over a considerable period when no other method is available. If the relation is based upon a large number and range of observations, it may give fair results for totals over long periods. At present the only satisfactory method of determining the best frequency of sampling is to study the watershed, stream, and rainfall characteristics with consideration of the type of investigation, and from that more or less arbitrarily specify the periodic frequency of routine measurements and the amount of intensive sampling necessary with various changes of stage, particularly of rising stages.

In addition to the importance of proper selection of verticals, the choice of points in each vertical, and the frequency of sampling, the reliability of the observer and the accuracy of the sampler itself are major considerations.

100. Study of sampling equipment--The study of the sampling equipment which has been used in the past included the collection of data on more than sixty-five samplers, covering a wide range of methods of entrapping the sample. From a study of these it was apparent that a grouping of the samplers was possible, since certain of them embodied the same principle or mode of action. Consequently the following grouping evolved, which proved advantageous in both discussion and presentation:

a. Vertical pipe samplers.

b. Instantaneous vertical trap samplers.

c. Instantaneous horizontal trap samplers.

d. Bottle samplers.

e. Time-integrating samplers.

f. Pumping samplers.

g. Photo-electric equipment.

During this study, certain features of the samplers were recognized to be advantageous and others to be objectionable. The most important have been presented in this report.

In most cases existing samplers were designed to satisfy specific requirements of a particular investigation, with the result that no single sampler or type of sampler has yet evolved which can satisfy the requirements of all sampling conditions. To serve as a guide to some extent in future sampler development, the requirements of the "ideal" sampler suitable for all conditions were set forth.

Two paramount factors in the selection of sampling equipment are:

> a. The instantaneous fluctuations of sediment concentration which may be of sufficient magnitude to result in serious errors in a determination of sediment discharge based on a single instantaneous sample. This factor should be given due consideration and compensated for either by number of samples collected from the same point, or by allowing a sufficient length of time to collect a single sample.
>
> b. Disturbance of flow lines in the sampling zone may result in a tendency to segregate the suspended sediment from the water and cause the sample to have a higher or lower concentration than the true value. Although an evaluation of the effects of the disturbance of flow upon the concentration has not been accomplished, this factor should be given consideration and sampling equipment should be selected which tends to collect the samples with a minimum of disturbance to the sampled water.

The instantaneous samplers, both the horizontal trap type, represented by samplers illustrated in Figs. 29 and 31 to 40, and the vertical trap type, represented at best by the Eakin sampler, Figs. 18 to 20, have been developed to an advanced stage with special consideration given to the reduction of the disturbance of the sampled water. They are particularly adapted to sampling in extremely deep and swift water. The horizontal trap samplers, because of their simplicity, ruggedness, ability to sample adjacent to the stream bed, and positive action, have been most widely used and stand out, in general, as the most important of the instantaneous samplers.

The time-integrating samplers, representing the latest development, theoretically collect the sample with a more or less smooth-filling action over a period of time, so as to obtain a sample representing a mean of the fluctuating concentration. This type of sampler can be relatively simple in design, compact and well adapted for use in ordinary stream conditions. Until further studies of flow into the time-integrating samplers are completed, it can only be stated that tendencies toward segregation of water and sediment are probably less pronounced if the intake faces directly into the stream.

In the depth-integration method of sampling, in which a sample is collected throughout the depth of the stream, none of the samplers used at present, result in a theoretically correct depth-integrated sample, because their rate of filling is not directly proportional to the stream velocity. The magnitude of errors resulting from their use is being given further study. The collapsible container type of time-integrating sampler, used to some extent in Russia, is said to fill at a rate proportional to the stream velocity, and thus obtain a theoretically true representative sample throughout a vertical. However, some investigators have found that in its present state of development it is not adapted to field use.

Pumping samplers, although used to some extent at more elaborate sampling installation sites, have not been developed to a practical stage for general field adoption.

The photo-electric method of determining sediment concentration has been tried by several investigators, but has been invariably abandoned as unsatisfactory because of the impracticability of evaluating the numerous variable factors.

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